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THE ENGLISH ELECTRIC JOURNAL

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PHOENIX WORKS, Bradford.
SIEMENS WORKS, Stafford.
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The ENGLISH ELECTRIC JOURNAL

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PHŒNIX WORKS, BRADFORD: SMALL AND MEDIUM MACHINE ERECTION DEPARTMENT.

PHŒNIX WORKS, BRADFORD: SMALL AND MEDIUM MACHINE ERECTION DEPARTMENT.

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CONTENTS.

	PAGE
PROGRESS NOTES - - -	71
THE PHŒNIX WORKS, BRADFORD	73
DIRECT-CURRENT GEARED TURBO-GENERATORS - -	82
STEEL WORKS DRIVES - -	92
OVERLOADS ON COMMUTATING MACHINES - - - -	99
OVERALL ECONOMY IN STEAM POWER STATIONS - - -	106

EDITORIAL.

All Communications respecting Editorial Contents should be addressed to THE EDITOR, THE ENGLISH ELECTRIC JOURNAL, QUEEN'S HOUSE, KINGSWAY, LONDON, W.C. 2.

PROGRESS NOTES.

THE BLACKBURN POWER-STATION.

On May 13th the Foundation Stone of the new Power Station of the Blackburn Corporation at Higher Whitebirk was laid by Alderman Thompson, the Chairman of the Electricity Committee. This ceremony marked the completion of the first stage in the execution of the comprehensive contract which has been placed with the English Electric Company for the erection and equipment of this station. Blackburn may, from its strategic position and its ultimate destiny as the principal source of supply to a large industrial area, be regarded as the first of the super-power stations. We propose at a later date, when the plant is erected and running, to print in this Journal a full description.

For the moment we content ourselves with the brief statement that the station will contain two 10,000-K.W. Turbo-Alternator Sets, and that the object aimed at throughout—in the constructional work, the electrical plant, the boilers, stokers, automatic coal-handling plant and all other details—has been to make the installation one of the most modern and efficient in the country.

AUSTRALIAN DEVELOPMENTS.

The English Electric Company of Australia, Ltd., recently commenced operations under that name. The Company represents the alliance and extension of two well-known Australian manufacturing Companies—the Standard Waygood Hercules, Ltd., of Sydney, and G. Weymouth Proprietary, Ltd., of Melbourne—both of which were engaged in the manufacture and sale of electrical and allied machinery. The new Company, which has a capital, locally subscribed, of £600,000, will develop the manufacture in Australia of these products to the designs of the English Electric Company, and will act as Australian representatives of that Company. New Works near Sydney are at present being built and equipped with the most modern plant for this purpose.

Standard Waygood Hercules, Ltd. have installed over 2,500 electric lifts in different parts of the Commonwealth and New Zealand, and during late years have manufactured a large proportion of the electrical and mechanical equipments in their own workshops in Sydney. They have also built refrigerating plants of all sizes for State Governments, municipalities and private Companies. G. Weymouth Proprietary, Ltd., have manufactured in Melbourne a large amount of electrical, pumping and hydro-electric machinery, in addition to the complete condensing plant required in connection with the electrification of the Melbourne Suburban Railways. Since the amalgamation of the two Companies, in 1919, they have obtained an important order for a complete 30,000-volt switchboard for the Sydney Municipal Council.

The English Electric Company of Australia, Ltd., will play an important part in the development of Australian industries and in demonstrating that there is no reason why heavy electrical machinery should not be manufactured in the Commonwealth. It has already secured an order for two 2,500-K.W. Turbo-Alternator sets, to be built mainly in Australia, for the New South Wales Government Railways and Tramways.

The Phoenix Works, Bradford.

The first two in this series of articles describing the several works now controlled by the English Electric Company, appeared in the January and April numbers of the Journal, and dealt with the Ordnance Works at Coventry, and the Dick, Kerr Works at Preston, respectively.

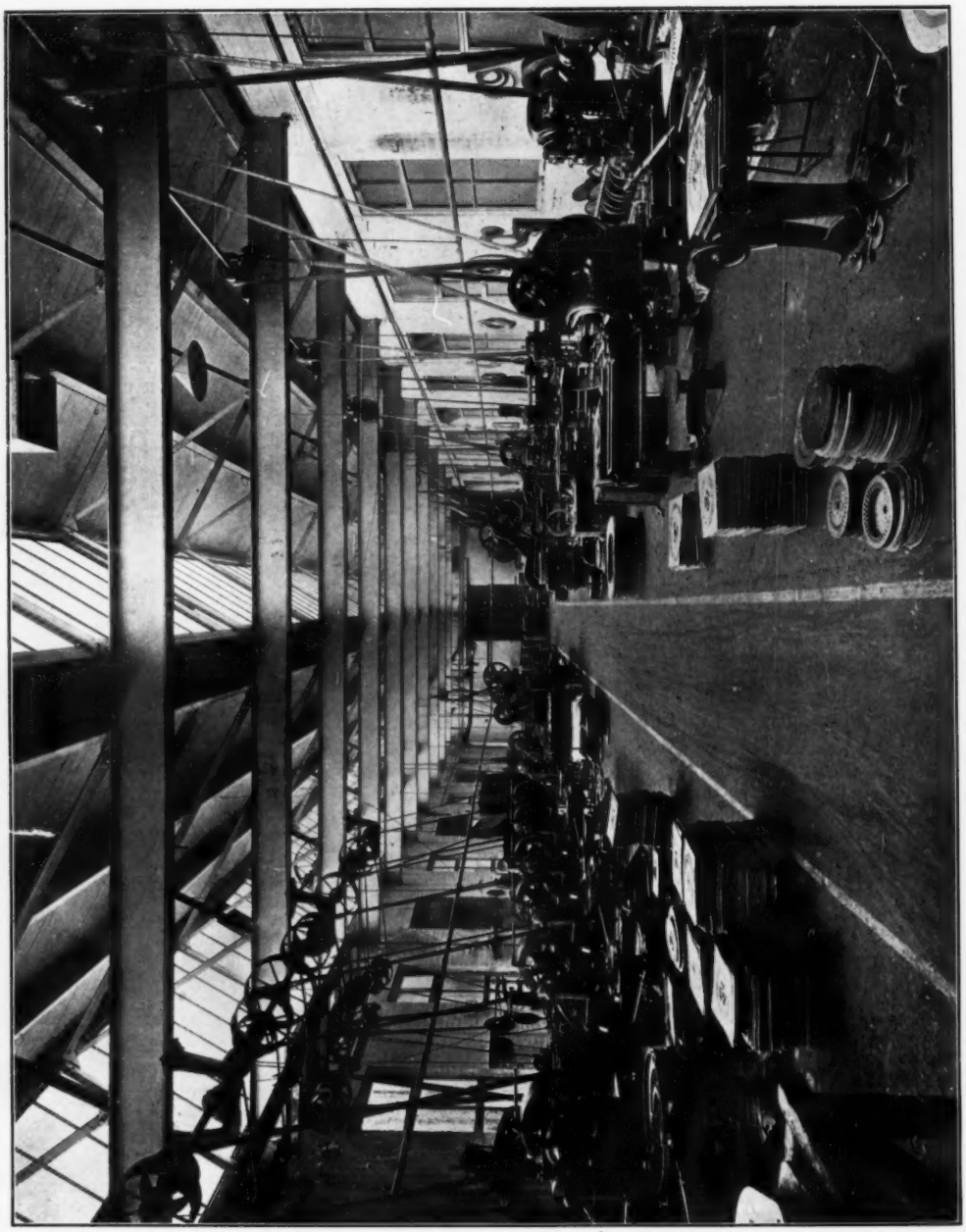
WINDING STORES.

IN THE PAST.

The Phœnix Works of the English Electric Company are situated at Bradford. From their inception, over twenty years ago, they have been planned for, and occupied with, the manufacture of the smaller classes of rotating electrical machinery.

In 1906 the development of electricity as a motive power for textile mills became more generally established, and the Phœnix Works, being situated in the very centre of the heavy woollen industry, evolved many special appliances for textile work. There are to-day in Yorkshire and Lancashire innumerable firms which began business between the years 1906 and 1910, and have now become great and powerful organizations. Electricity can claim in many industries, but particularly in the textile trade, to have emancipated the small capitalist. If it had been necessary to purchase an engine, boiler, and the necessary power generating equipment, a great many of the younger men could not have procured sufficient capital to start a factory of their own. The growth of the Phœnix Works, coincident with that of the smaller type of textile factory in the Yorkshire district, is a significant illustration of the mutual benefit to engineering firms and manufacturers which may accrue from a cheap supply of electricity and a type of operating plant designed specially for any particular industry.

By virtue of their geographical position in



STAMPING DEPARTMENT.

AUTOMATIC MACHINE DEPARTMENT.

the Yorkshire coalfields, the Works almost automatically began to specialise on the application of electricity in coal mines. The inefficiency and cost of maintenance of compressed air machinery as a means for operating coal cutters and other portable machinery under ground, led to a very considerable increase in the use of electricity below ground and in fiery mines. This

SECTION OF WINDING DEPARTMENT.

necessitated an unusually close co-ordination between the manufacturer of motors for this purpose and the coal mining expert. One or two accidents, of which the cause was obscure, in the coal pits in which electricity was employed under ground, led to a real and not unnatural opposition on the part of the miner to this new form of power. The Phœnix Company appreciated that the whole subject was worth very special consideration, not only from the point of view of the theoretical efficacy of the explosion proof motor, but because it was essential to devise some form of test which would convince not only the coal owner but the miner himself that the safety of the machine upon which his life depended was without question. After many experiments the machine was designed and put upon the market, and an experimental explosion chamber was installed at the Works. Both the coal owners and the men's representatives were pressed to witness actual tests in an atmosphere similar to that of a fiery mine. It is claimed that, at any rate in the Yorkshire and Lancashire coalfields, this practical demonstration did much

LARGER MACHINE ERECTION DEPARTMENT.

SMALL AND MEDIUM MACHINING DEPARTMENT.

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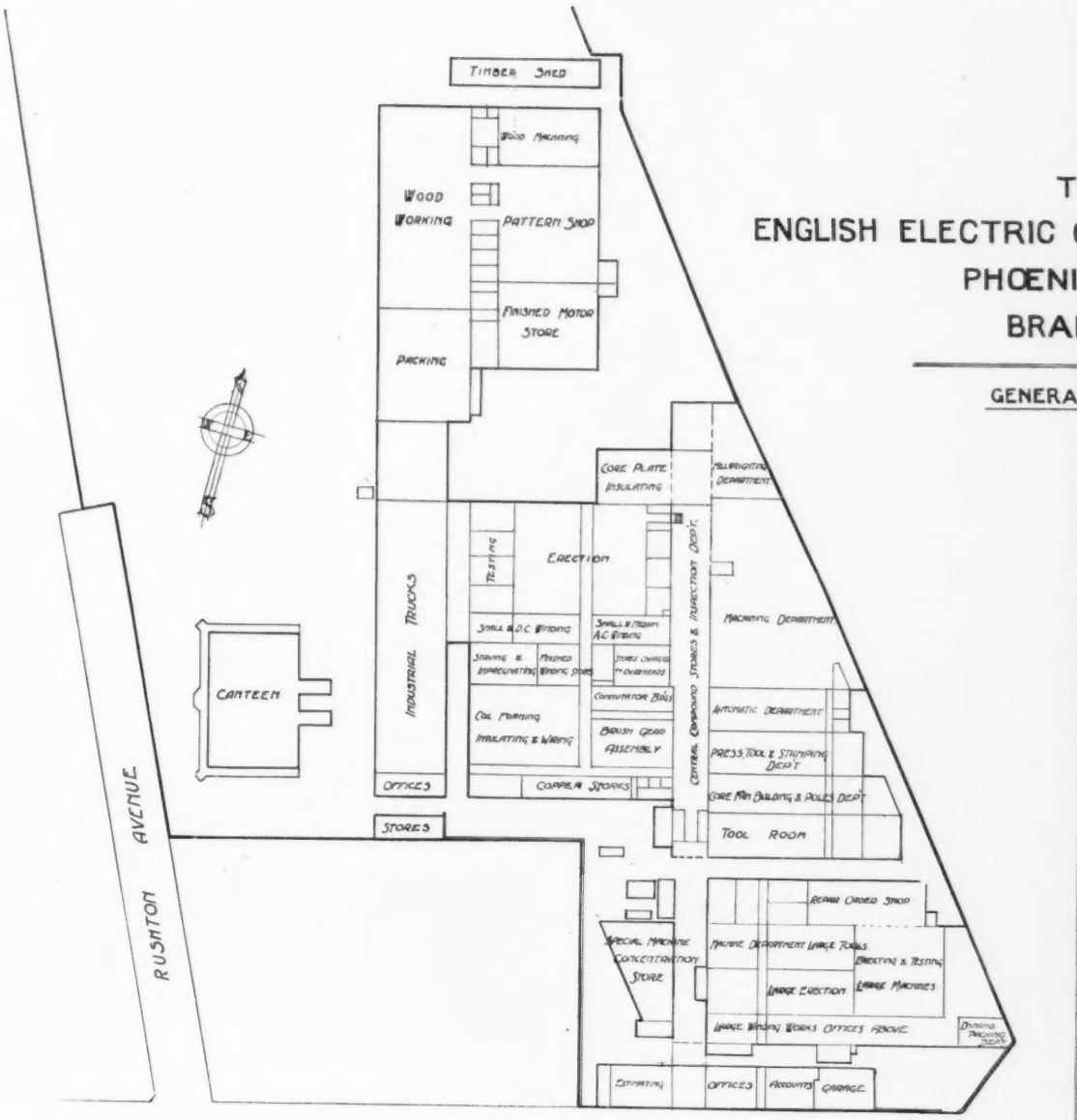
ENGLISH ELECTRIC C
PHOENIX
BRAD

GENERA



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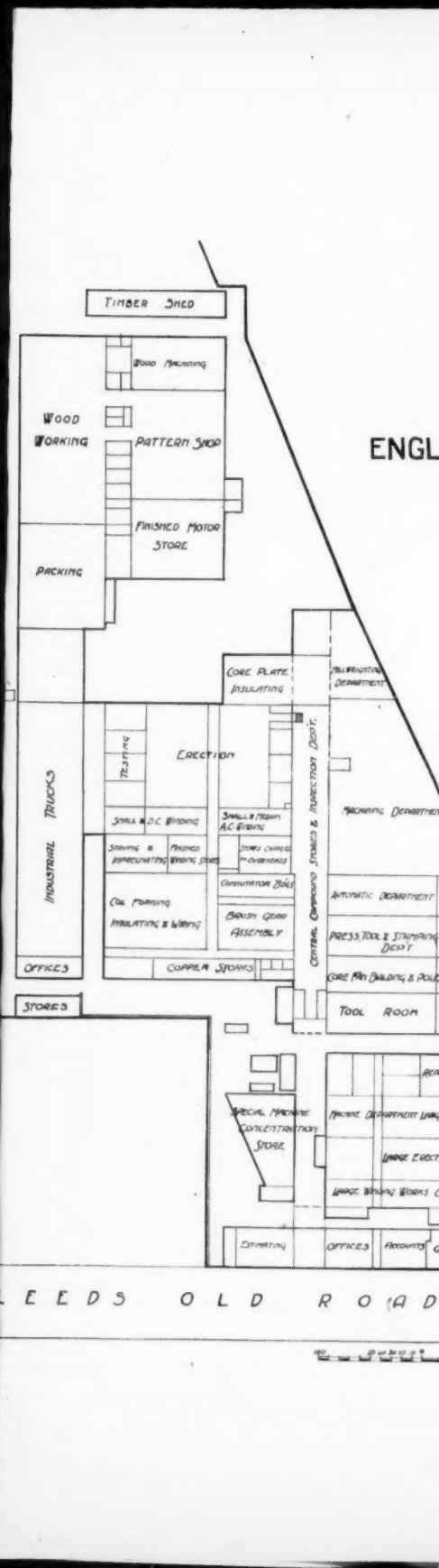
TIMBER SHED
WOOD MACHINING
WOOD WORKING
PATTERN SHOP
FINISHED MOTOR STORE
PACKING
CORE PLATE INSULATING
ERECTION
TESTING
SMALL A.C. WINDING
INDUSTRIAL TRUCKS
OFFICES
STORES
COMMUTATOR BARS
COIL FORMING INSULATING & WIRING
BRUSH GEAR ASSEMBLY
COPPER STORES
CENTRAL COMPOUND STORES & DIRECTION DEPT.
AUTOMATIC DEPARTMENT
TOOL ROOM
SPECIAL MACHINE CONCENTRATION STORE
ESTIMATING
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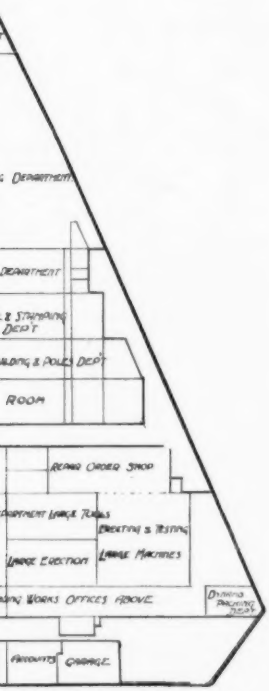
THE

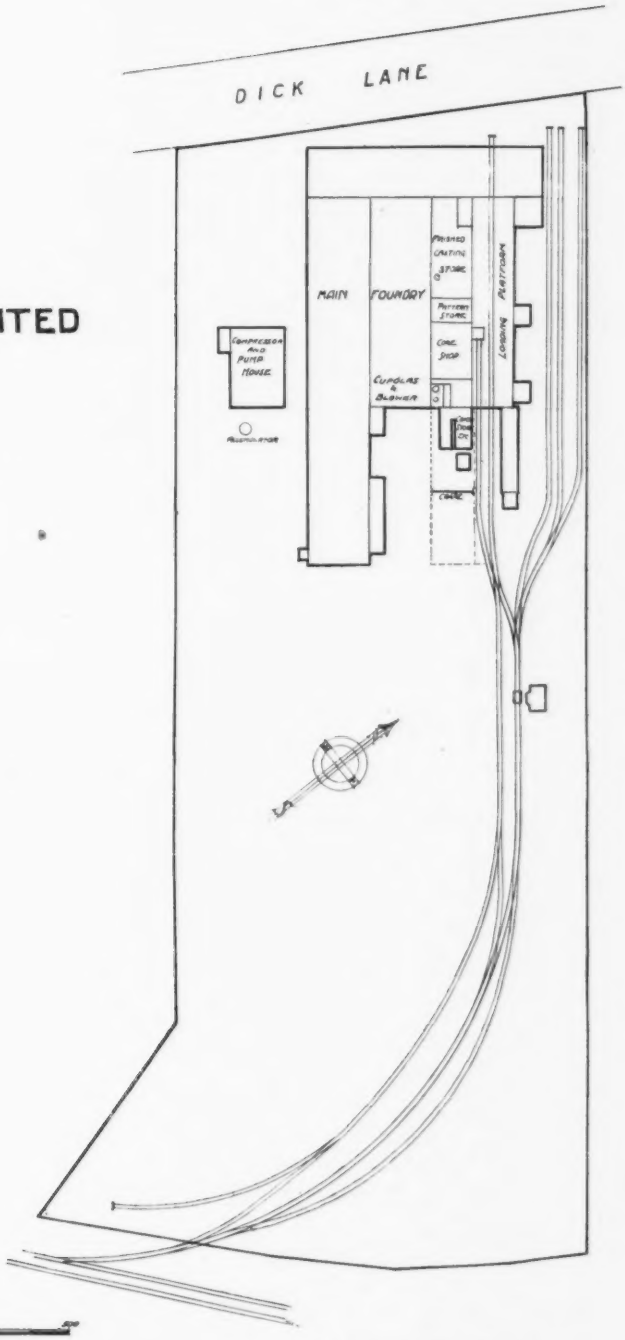
NGLISH ELECTRIC COMPANY LIMITED

PHŒNIX WORKS

BRADFORD

GENERAL PLAN

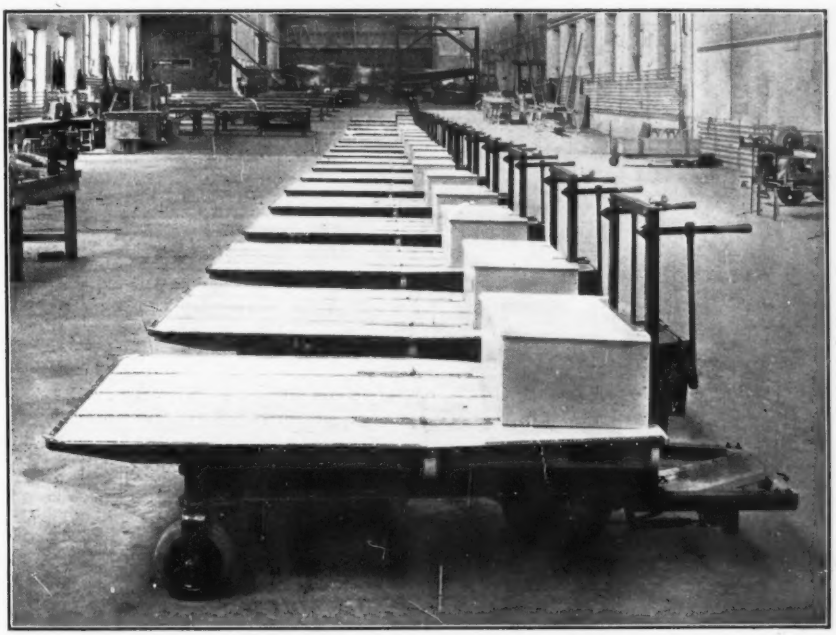




SCALE OF FEET :

: DICK LANE WORKS :

to remove the quite natural fears of the miner, and accelerate the more general application of electricity below ground. From this date onwards, every motor of this type has been tested in the manner just described, and the buyer has been invited to witness such tests. The type of machine was standardized at Bradford and secured a ready sale. The development of special impregnation and insulation for mining purposes, particularly in the use of open type motors for screens and



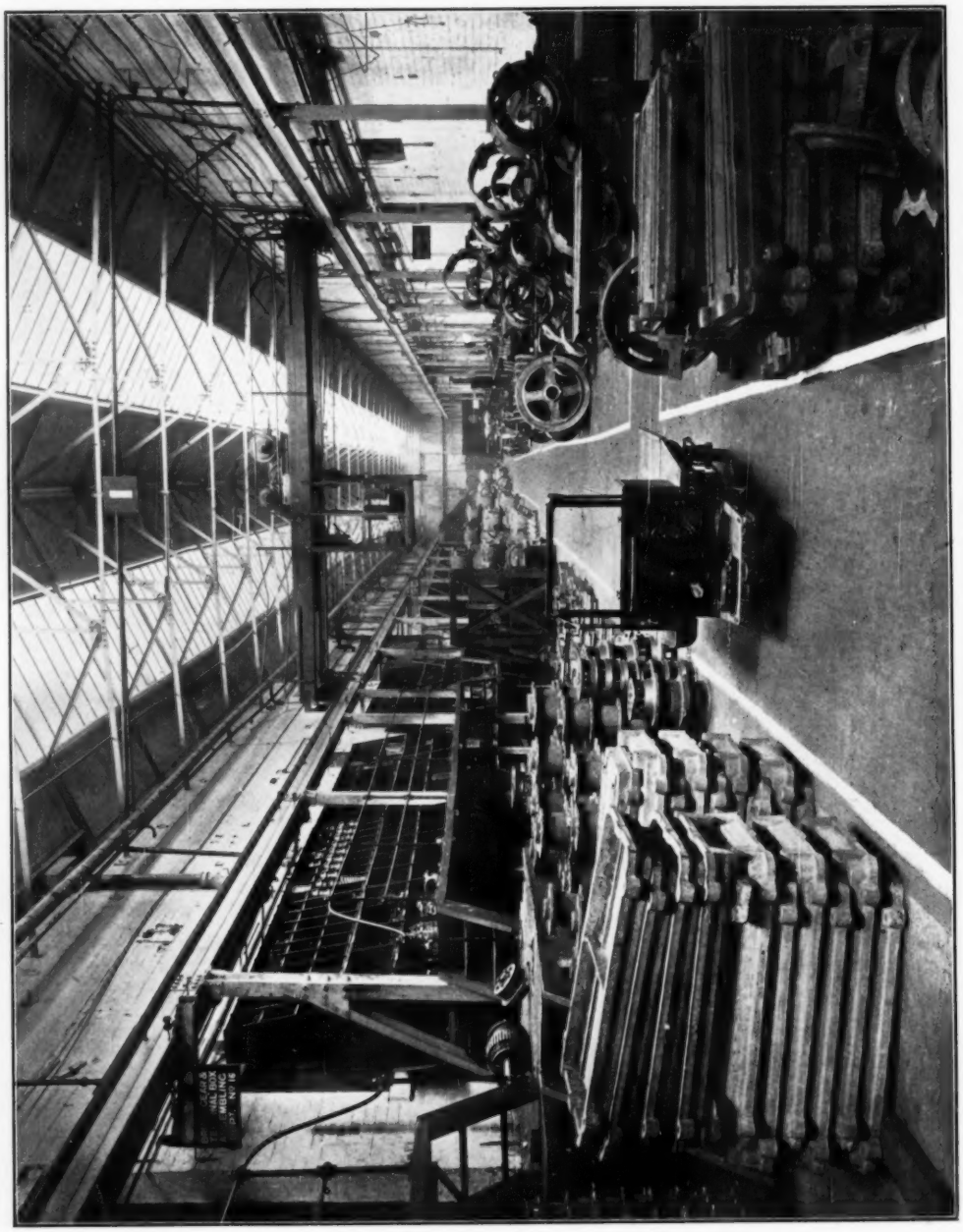
ELECTRIC TRUCKS AT BRADFORD.

other dusty positions, has resulted in a virtual elimination of the fully enclosed motor of large size from this class of work.

TO-DAY.

One of the aims of the English Electric Company is to secure efficiency by dividing the manufacture of the Company's products into certain ranges of size and type, and manufacturing the total requirement of a particular article at one works. This principle has made it possible to remove from the Phœnix range all larger sizes of electrical machinery, thus occupying the factory solely on machines for which it was expressly laid out. It was on products of a repetitive character that the Works were employed before the war, and the cessation of hostilities left the factory and its plant well equipped for a larger and more intensified output of small standard electrical machinery. The general scheme of the lay-out will be obvious from the block plan printed with this article.

Goods are received and despatched at a rail-head running into the Great Northern main line, and having considerable siding accommodation. Here also is a foundry specially equipped for repetition work. Its capacity is such as to make it possible to manufacture the whole of the light repetition castings required by the entire group of works. It is equipped with automatic sand-handling devices and a number of moulding machines, and it is hoped, by the introduction of every known labour-saving device, to increase the foundry output of



CENTRAL STORES AND INSPECTION DEPARTMENT.

the group without a proportionate reduction in the capacity for larger and more complicated castings which can only be produced by the aid of highly-skilled moulders.

The manufacturing plant proper is at the original Thornbury Works, and the main scheme of the lay-out will be apparent from the plan accompanying this description. It will be noticed that a bay 600 ft. in length bisects the works. This is the Central Store, into which all materials are received and from which they are issued to the manufacturing departments and returned after completion for inspection and transfer to the assembly shops. The machining and detail sections of the works are on the right-hand side of the central bay and the assembly department on the left-hand side.

One effect of the very large amount of repetition work handled during the war has been to intensify the necessity for very extensive jigs of every known device for saving labour: the contraction of the range of products manufactured at Bradford has further intensified the possibilities of increased efficiency in this direction, and whilst the expression "mass production" has become, since the war, a misnomer in British engineering, every effort is being made to secure to the highest possible degree the efficiency resulting from a reduction in the number of standards. No attempt is being made to force upon the purchasers in this country and abroad a higher degree of standardization than the immense variety of the applications of industrial electrical machinery will allow. It should not, however, be overlooked that whilst there does not appear to be any parallel between the complete standardization enforced in the production of a Ford motor car and an electrical machine, every modification from a reasonable standardization enforced by the buying public results directly in an increased cost of, and a proportionate restriction in, the general application of electricity to industrial purposes.

The Automatic Department is equipped with full automatic turning machines for dealing with the bar and chucking demands of the electric motor business. Steel is very largely used for the frames of direct-current motors, the resultant lightness being considered of great importance in view of the increased cost of transport for foreign work.

Increase in the application of electricity to textile factories renders the favourable geographical position of the Bradford Works to the textile industry in general a very great factor in the type of work there undertaken. The amalgamation of the joint experience of the associated firms, placing the company, as it does, in a position to supply the complete mill equipment, generating plant as well as motors, has already resulted in a large number of such complete schemes being carried out by the Company.

Adjacent to the works is the Phœnix Park, a sports and recreation club for the use of the employees of the Works and their families. The park, which was formerly a farm, covers 70 acres, and now includes cricket and football grounds, bowling greens and a nine-hole golf links. The converted farmhouse and buildings are used for social purposes. The club is managed by the men themselves through the Phœnix Park Association, the capital of which was entirely subscribed by them.

Direct-Current Geared Turbo-Generators.

Amongst the most interesting of the recent manufactures of the English Electric Company is the 6,000-K.W. Direct-Current Generator Set recently installed at the City of London Electric Lighting Company's Power Works at Bankside. This set, which is illustrated in the accompanying figures, claims attention for various reasons, but the chief of these is that its output is the largest yet obtained from a direct-current geared turbo-generator set.

It is common knowledge that the output of the direct-current generator driven by slow-speed reciprocating engines is limited by two inter-dependent factors—space and cost. This is due to the fact that as the output of reciprocating steam engines increases, their most effective running speed decreases, and as no efficient type of gearing for large power units had been introduced until recent times, this meant that one was forced back on slow-speed generators, and in order to increase the output of the machine, the necessary peripheral speed of the armature could only be obtained by increasing its diameter. In this way a limit of output was soon reached beyond which the machine became altogether too cumbersome. The introduction of the steam turbine reversed this state of affairs completely. Here it was found that the most efficient speed of the prime mover was too high for the direct-current generator. The chief difficulty encountered in this direction was commutation. Commutation at anything above a certain peripheral speed of the commutator becomes a matter of the greatest intricacy, in as far as the slightest tendency of the shaft to rock or "whip" causes the brushes to jump over complete segments, with the result that serious sparking inevitably ensues. On the other hand, a certain cross-sectional area of commutator segments was essential, owing to the heavy currents being collected by the brushes, and for this reason machines with exceptionally long commutators were introduced in which the commutators were built up in two, and often in three, sections. This necessitated the introduction of two or three sets of brushes and various other complications.

These manifold objections led to a considerable decrease in the demand for large direct-current generators. The introduction of the geared turbine, however, has brought this demand back to its previous level, and the demand is, in fact, rapidly becoming greater than any hitherto experienced for this type of machine. The great practical advantages of the geared turbo-generator set lie in the facts that the turbine is so highly superior in every way to the reciprocating engine as a prime mover, and that the gear ratio for the set can be so chosen that both the turbine and the generator are made to run at their maximum economical speeds. This means, among other things, that the weight of the machines can be considerably reduced, as shewn in Fig. 3.

The English Electric Company Direct Current generating set installed at Bankside is an instance of the high level to which modern design has raised the direct-current geared turbo-generator. It has an output of 6,000 K.W. at 460/500 volts, and consists of two 3,000-K.W. D.C. machines in tandem. The turbines run at 3,000 R.P.M., and the generators at 300.

The prime mover consists of two Parsons' turbines of the pure reaction type, each coupled to a gear pinion. The cylinders are placed side by side, so that both pinions drive the same gear wheel—one on either side of the horizontal centre line of the wheel—to which the tandem generators are coupled. The steam passes through the two turbines in series, the high-pressure cylinder taking steam from the boilers and expanding it to approximately atmospheric pressure. A U-pipe underneath the turbines connects the high-pressure exhaust to the inlet of the low-pressure cylinder in which the expansion is continued down to the condenser vacuum. This arrangement of turbines has many definite advantages in the case of D.C. plants of large output such as the Bankside installation. The division of the expansion of the steam into two cylinders renders it possible to keep the overall length of the turbines very short, whilst the duplication of the pinion halves the width of tooth-face required on the gear wheel, so that the gear is also very compact. Further, the side by side turbines are just the same width overall as the large diameter generator magnet frames. The complete plant is thus both short in length and uniform in width, so that the greatest possible economy of power-station floor space is effected. Moreover, these practical

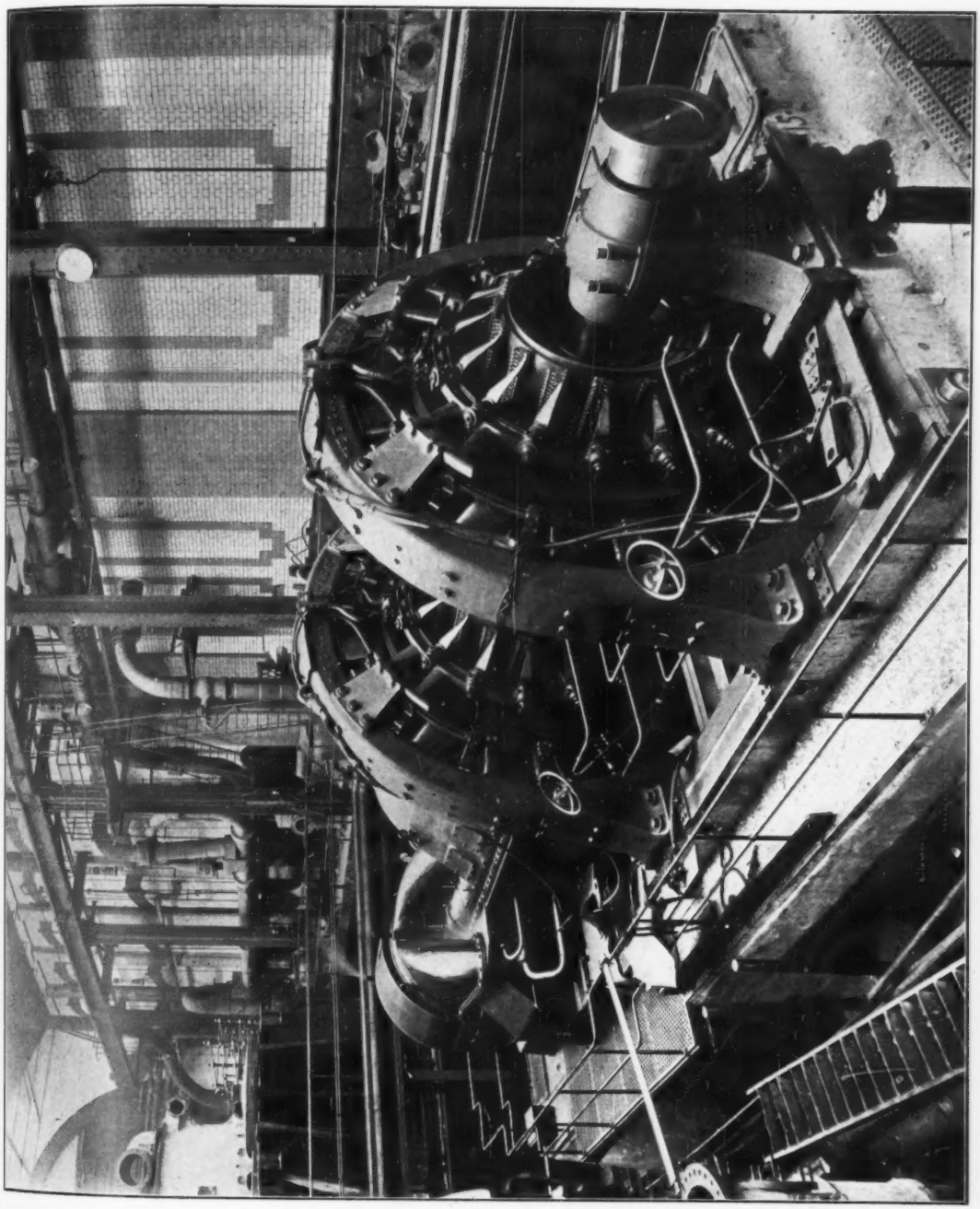


FIG. 1.—COMPLETE VIEW OF ENGLISH ELECTRIC COMPANY 6,000 K.W. DIRECT CURRENT GENERATOR SET, DRIVEN BY PARSONS' TURBINES THROUGH 10 : 1 GEARING (UNDERGOING FULL-LOAD TEST ON SITE).

advantages are obtained without prejudice to the thermal efficiency of the turbines, for as the full quantity of steam passes through both cylinders full advantage can be taken of the principle of multiple stage expansion from which the very high efficiency of reaction blading is derived.

The plant is designed for a steam pressure of 160 lbs. per square inch, and a superheat of 200° Fahr., at the turbine stop valve, and a

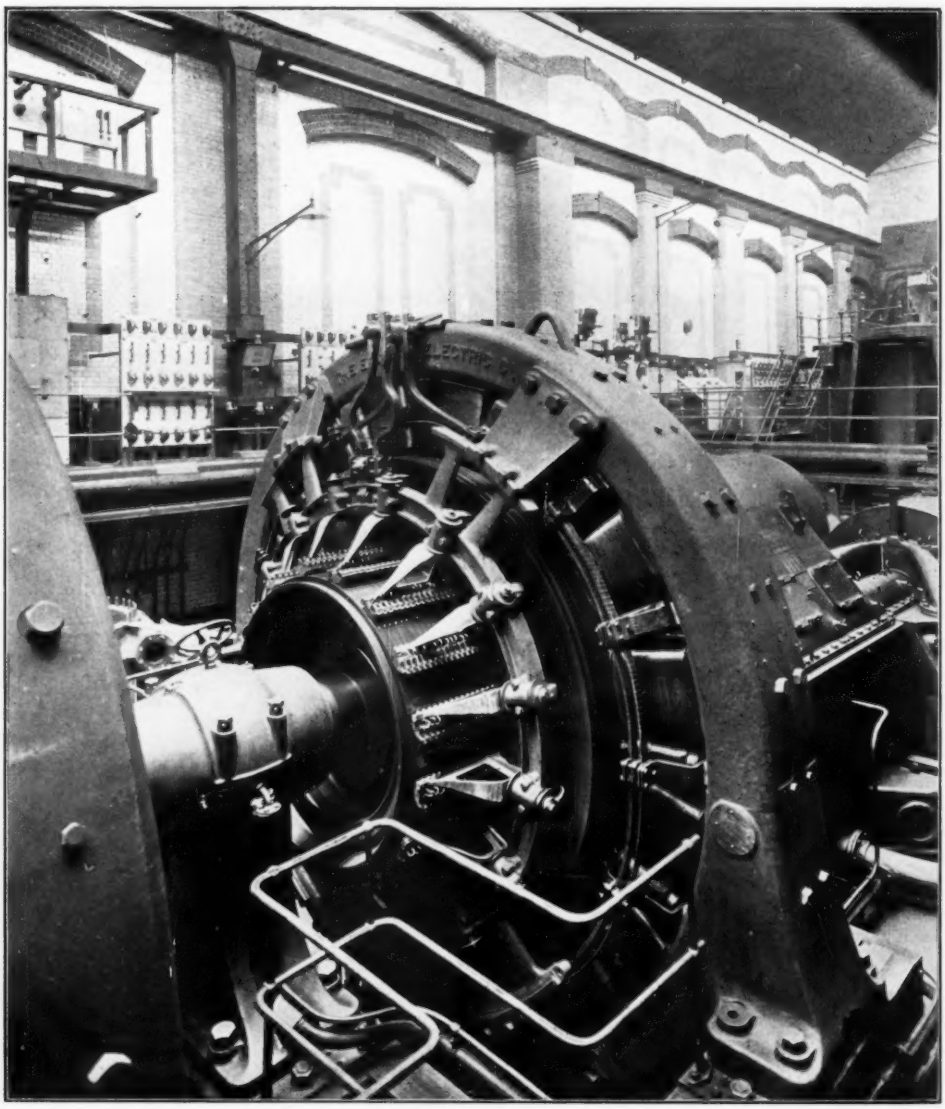
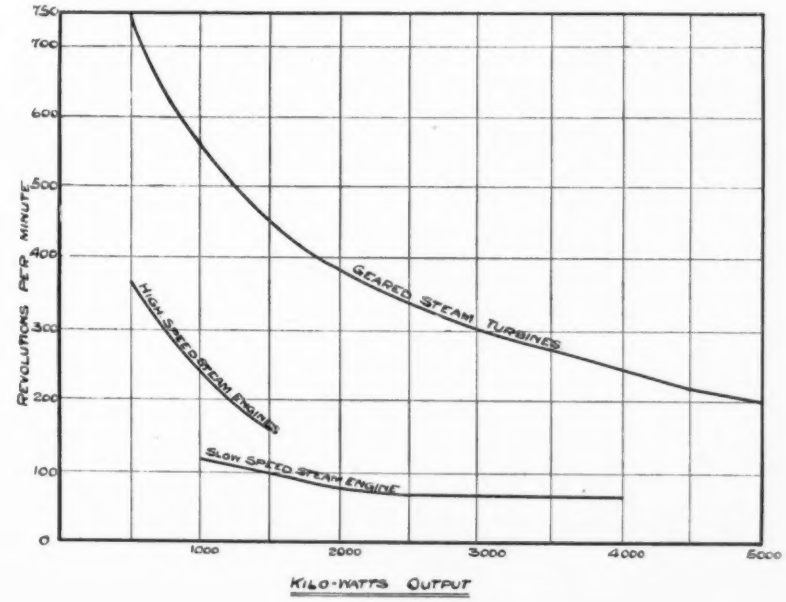


FIG. 2.—VIEW OF COMMUTATOR END OF SINGLE MACHINE (UNDERGOING FULL-LOAD TEST ON SITE).


REVOLUTIONS PER MINUTE
750
700
600
500
400
300
200
100
0
GEARED STEAM TURBINES
HIGH SPEED STEAM ENGINES
SLOW SPEED STEAM ENGINE
1000
2000
3000
4000
5000
KILO-WATTS OUTPUT

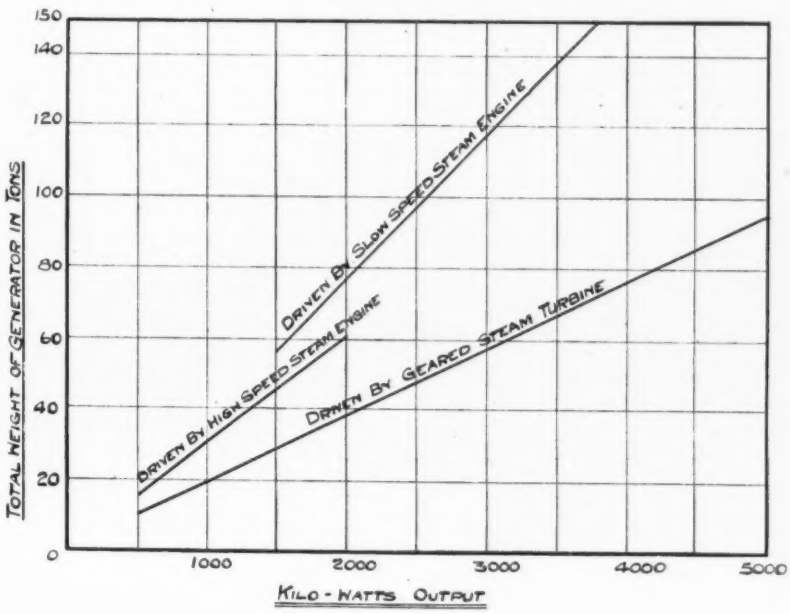

TOTAL HEIGHT OF GENERATOR IN TONS
150
140
120
100
80
60
40
20
0
DRIVEN BY SLOW SPEED STEAM ENGINE
DRIVEN BY HIGH SPEED STEAM ENGINE
DRIVEN BY GEARED STEAM TURBINE
1000
2000
3000
4000
5000
KILO-WATTS OUTPUT

FIG. 3.

condenser vacuum of 28·7", and as mentioned above, the pressure in the inter-connecting pipe between the cylinders is approximately atmospheric. About half the available heat drop therefore is utilised in each cylinder, and the total power developed is equally divided between the two. The blading is of the axial clearance or "end-tightened" type throughout the high-pressure cylinder. In this type of blading a shroud is fitted all round the tips and projects beyond the edge of the blades. The projecting portion is thinned down to a "knife edge," and runs nearly in contact with a barrier formed by the spacing pieces of the adjacent row of blades. Both in cylinder and spindle the spacing pieces are arranged to stand proud of the grooves in which the blades are secured, so as to form the barrier against which the shroud of the corresponding row of spindle or cylinder blades can run. Steam leakage being effectively prevented by this axial seal, the radial clearance can be made as large as desired, and all danger of contact between the tips of the spindle blades and the cylinder bore—should the high temperature cause any distortion of the castings—is completely eliminated. The precision with which this axial clearance can be adjusted reduces the loss through clearance leakage very considerably in comparison with that over the blade tips in radial clearance blading, and for this reason end-tightening is also adopted for the major portion of the blading in the low pressure turbine, although here, as the cylinder is not subjected to high temperature, no distortion is likely to occur. Accurate setting of the axial clearance is provided for by an adjustable thrust block in which a collar on the spindle is located between pivoted white metal pads. One dummy only is provided in each cylinder to balance a proportion of the end thrust, the remaining unbalanced axial force being taken on the thrust block.

The speed governor is of the centrifugal type and is driven by a worm and worm wheel from the high pressure turbine spindle. It controls the main inlet valve by means of a steam relay mechanism and overload is provided for by an automatic steam controlled byepass valve. A runaway valve is fitted in the steam chest and is automatically closed should the turbine speed exceed a specified limit. A centrifugal control mechanism is fitted on each turbine shaft, the arrangement being such that each is capable of "tripping" the runaway gear independently.

The gearing is of the well known Parsons double helical type with a speed reduction from 3,000 to 300 R.P.M. The teeth are at an angle of 30° with the line of contact and are cut by the "creep gear" process which contributes so largely to the high standard of reliability now obtained by high-speed noiseless reduction gear for high power transmissions, and which is too well known to need detailed description. The pinions are made from solid nickel steel forgings and are driven by the turbines through flexible couplings, which permit of axial movement of the pinions relative to the turbine shafts, so that the former are free to float between the two tooth faces of the gear wheel, which ensures an equal division of the load between the two spirals. Each pinion runs in three bearings carried in housings provided in the gear case itself. The gear wheel is of cast iron, the teeth being cut in steel rims shrunk on to the wheel casting. The generators are driven through a rigid flange coupling from the gear wheel shaft.

The generators are of the standard design manufactured at the Dick, Kerr Works, Preston, and their frames are of cast iron. The external diameter of these is a little under 15ft., while the width of the frame proper is about 20 inches, and the weight of the electrical part of the set is a little over 100 tons. Each machine has 16 main poles built up of laminated steel, and 16 interpoles of cast steel. The main fields are shunt wound, and consist of double cotton-covered wire wound on to insulated metal spools. The interpoles are wound up of strip copper on edge, insulated with paper and mica, and mounted on insulated metal spools.

One of the difficulties frequently encountered in large machines of this type is that the main current is too heavy to pass directly around the interpoles connected in series across the terminals. In this case, for instance, the main current of each machine is 6,000 amperes, consequently if the interpoles were connected in series across the terminals, each turn would give 6,000 ampere turns, and this would make it quite impossible to obtain the correct field strength without the use of a heavy diverter. This, however, would be unsatisfactory, since the field would be inductive and the diverter non-inductive, so that a change in the main current would not make a proportional change in the interpole circuit.

The method adopted on these machines to overcome this difficulty is to wind the interpoles in parallel, and in this way only the equivalent of the current generated by each circuit on the

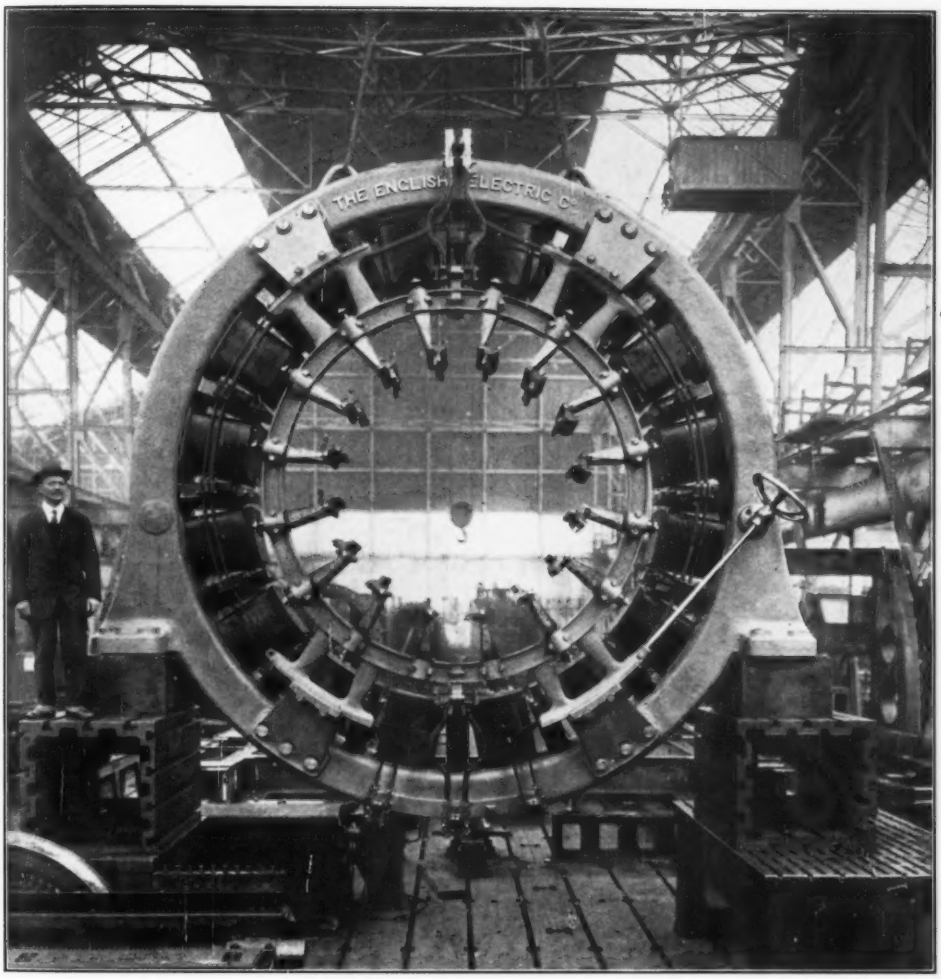


FIG. 4.—NEAR VIEW OF MAGNET FRAME AND BRUSH GEAR, AS ASSEMBLED AT ENGLISH ELECTRIC COMPANY'S COVENTRY WORKS.

armature is allowed to flow through each pole. In order to obtain an even distribution of the main current over the whole set of interpoles, the rings connecting the interpoles in parallel are built up of copper strips and graded, as shewn in the accompanying sketch (Fig. 5). A complete connecting ring of this kind would, however, form a strong magnetic field, the lines of which would be cut by the shaft and set up shaft currents. For this reason the ring is split up and taken around the frame in two opposing halves, each leading from the top of the machine to the bottom, and this completely neutralises any magnetic effect that would otherwise set up currents in the shaft.

The distribution of flux in an interpole

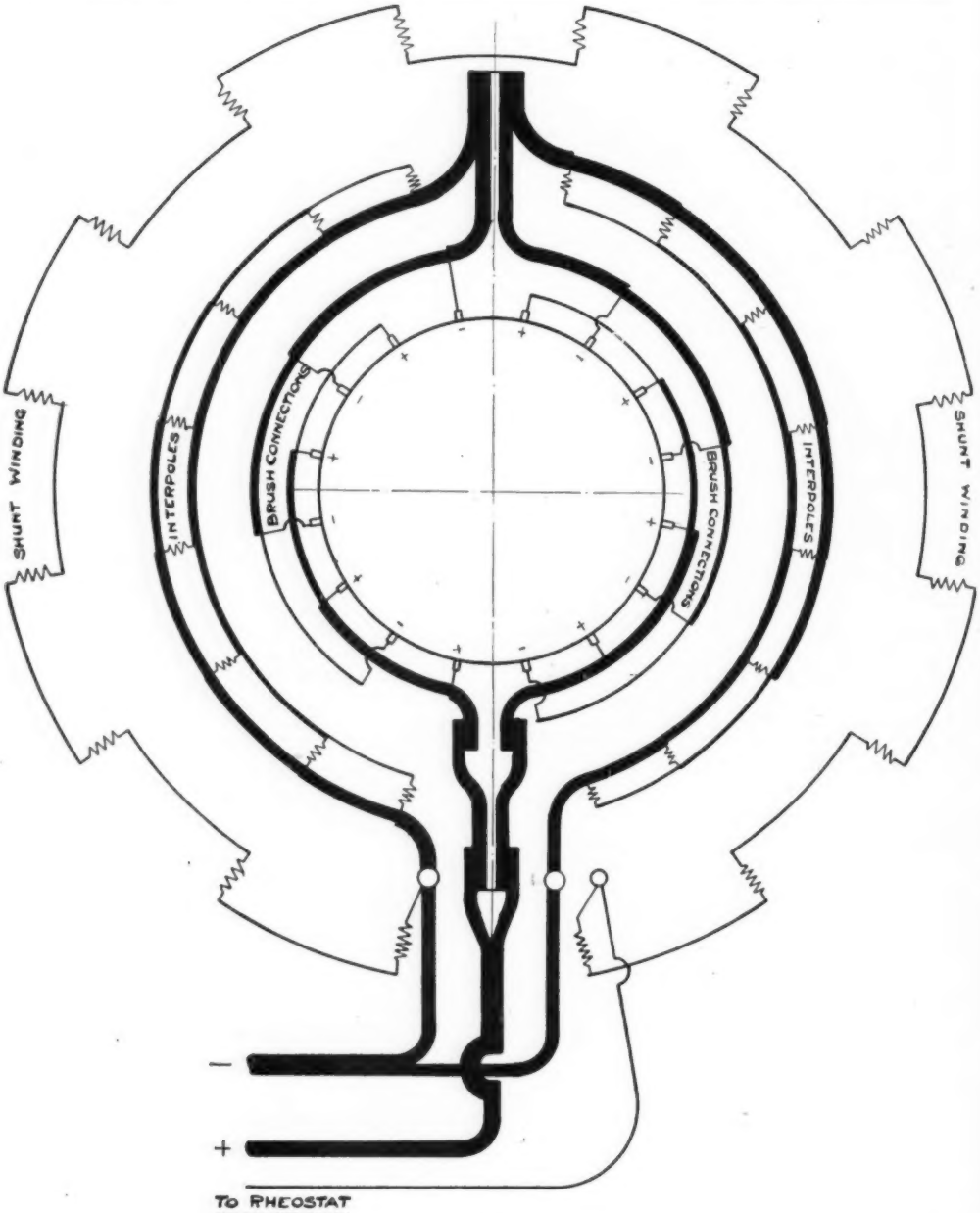


FIG. 5.—DIAGRAM OF CONNECTIONS SHEWING GRADED COPPER STRIPS CONNECTING INTERPOLES IN PARALLEL.

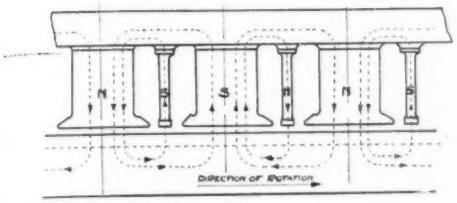


FIG. 6.

machine is illustrated diagrammatically in Fig. 6, and it will be seen from this that the linkage of the main and interpole flux is such that the total flux in the main pole air gap is the sum of the two fluxes. As the voltage generated by the machine is proportional to the strength of the field in the main air gap, it is obvious that quite a considerable compounding effect is obtained in these machines where the interpole flux approaches from 5 to 10% of the main flux. This effect is more pronounced if the machine is provided with compensation windings as well as with interpoles. In the set under discussion it was desired to run the new generators in parallel with two other machines already installed. These were shunt wound 1,800-K.W. sets driven by slow speed reciprocating engines, and their voltage drop on load was considerable, whereas that of the turbine set was very small. This effect is illustrated in Fig 7. The result of this was that when the two generator sets were first started up in parallel, the turbine set took more than its share of the load, which increased the interpole current, and consequently the interpole field, to such an extent that over-compounding resulted, which in turn led to an increase of voltage and a consequent increase of the main current, interpole current and field, and so on, until the new generators were carrying practically the entire load of both sets. A temporary diverter was at once introduced into the circuit to divert some of the main current from the interpoles, and to give only the exact amount of interpole field required for sparkless commutation and even parallel running. Provision was made for this diverter, which may be seen connected up in Fig. 1, in designing the machines, and the interpole shoes were made easily removable without interfering with the frame or the armature. In order to reduce the excessive interpole field produced as described above, the interpole shoes were slipped off and planed down so as to lengthen the air gap and reduce the field. The objection which next had to be encountered, however, was that owing to the increased length of air-gap the interpole field became unsteady, and swayed from side to side when the machine was run on load, causing considerable difficulty with the commutation. This was finally overcome by introducing thin aluminium packing plates in between the interpoles and the frame, so as to steady the field by shortening the actual air gap, while at the same time obtaining the necessary increase in reluctance in the magnetic circuit. This was finally successful, and when the adjustment was complete and perfect parallel running assured, the temporary diverters were removed, and the machine left in its permanent running condition.

The armatures are 108 ins. diameter by 16ins. long, with four $\frac{1}{2}$ in. air ducts. The peripheral speed of an armature of 9 ft. diameter, rotating at 300 R.P.M., works out at about 8,500 ft. per minute, which means that the mechanical stresses set up in the armatures are exceptionally high. For this reason, the spiders which carry the armature laminations are of an exceedingly robust design, as shown in Fig. 8. They are constructed of cast steel, and it will be seen that the arms are girder shaped and exceedingly massive. The general arrangement is shown in the sectional view (Fig. 2). The main point of interest in this connection is the arrangement of the balance rings fitted to connect up the points of equal potential on the armature windings with one another. These are usually fitted on the front or back armature end plate, and are built up of flat copper held in clamps, which has a special tapping on to the armature winding at each point of equal potential. There are three objections to the application of this method to

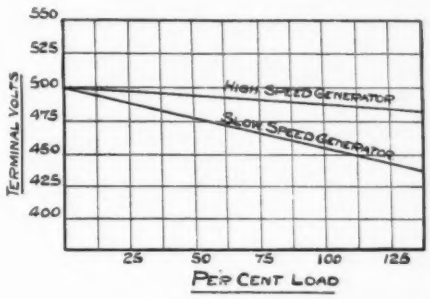


FIG. 7.

FIG. 8.—ARMATURE READY FOR WINDING.

these machines. First, it provides an arrangement which is very difficult of access; secondly, it does not lend itself to solid mechanical construction for high speeds; and thirdly, it introduces extra joints, tappings on to the back end of the armature and other objectionable features.

In this case, therefore, a new method of connecting up the balance rings was introduced. The rings themselves were simply constructed as half loops of strip copper, formed and insulated in the same way as the armature conductors, and wound on an insulated seating in the front end plate, as shown in Fig. 9. This winding is put on before the armature conductors, and the clamping arrangements for these also hold the balance rings in position. The balance ring windings are then connected into the commutator riser bars, and for this purpose the sweating loops of the riser bars are left longer by the required amount. This design has been found to work satisfactorily up to peripheral speeds of 18,000 ft. per minute.

The commutator is of the plain V-ring type and has an external diameter of 60 ins. and an active face of 22½ ins.

The brushgear is extremely robust, and is carried from the frame as shown in Fig. 4. The sixteen brush arms are insulated with thick sleeves of Ivoride held in clamps. This arrangement avoids the taking of live bolts through earthed portions of the machine and gets rid of the usual insulating washers and brushes so frequently a source of trouble. If, as the brush gear is arranged in this set, it is at any time necessary to remove a brush arm, all that is required is to remove the clamp on the outside of the brush ring, and the whole arm, with its insulating sleeve complete, comes away, and after the repairs have been carried out, it can be just as easily replaced.

The brush rocking device is of the standard Dick, Kerr design; the brush ring, which is of cast iron, is carried upon four arms from the frame as mentioned above, and each of the arms is clamped on to the frame by means of three 1¾" bolts. The rocking is effected by means of the hand wheel and pillar shewn in Fig. 4.

The bearings carrying the armature shaft are in this case somewhat different from the Dick, Kerr standard bearings, since they were built to suit the requirements of Messrs. C. A. Parsons, who supplied the turbine and gearing.

The machines are cool running in service, and there is ample margin to meet the specification. The efficiencies of each generator, including all mechanical losses, and the friction of one bearing as obtained from the summation of losses on test, are:—

Output in terms of full load	5/4	4/4	3/4	2/4	1/4
Efficiency %	95½%	96%	95½%	94%	88½%

It is not unusual for large sets to raise points of exceptional interest in their design, manufacture and erection, but it may be said that this

particular set raised considerably more than most. It was imperative that the machines should be in service by January, 1920, and all the castings except one brush rocker and the bedplate were well in hand and finished in good time for this purpose. So would the exceptions have been, had the moulders not decided to strike in September, 1919. This decision, and the protracted inactivity—from the productive point of view—of the moulders which followed it, threatened to prevent the starting up of the machines to the required date. However, the City of London Electric Lighting Company's engineers designed and built up a bedplate entirely made up of channels and girders, and the Preston Works made up the missing rocker of angle irons and forgings, both of which were used to put the machines into service, and both of which served their purpose admirably. Since the moulders' strike ended, the brush rocker has of course been replaced by one of the original design, but so satisfactory has the other invention, born of necessity, proved in service, that it has been decided to retain it in use.

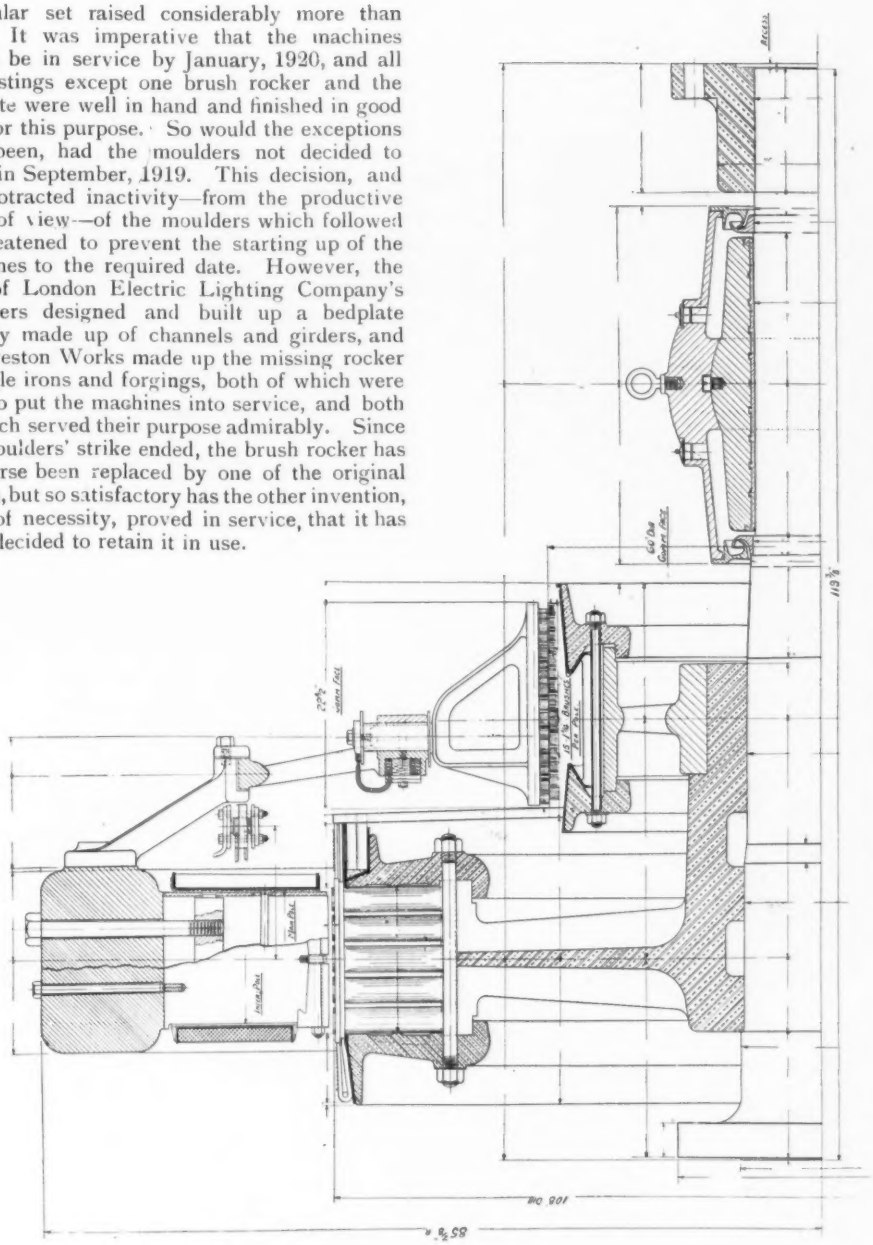


FIG. 9.—SECTIONAL VIEW OF ASSEMBLED MACHINE.

Steel Works Drives.

Reversing Motor Drive for a 34" Roughing and Finishing Mill.

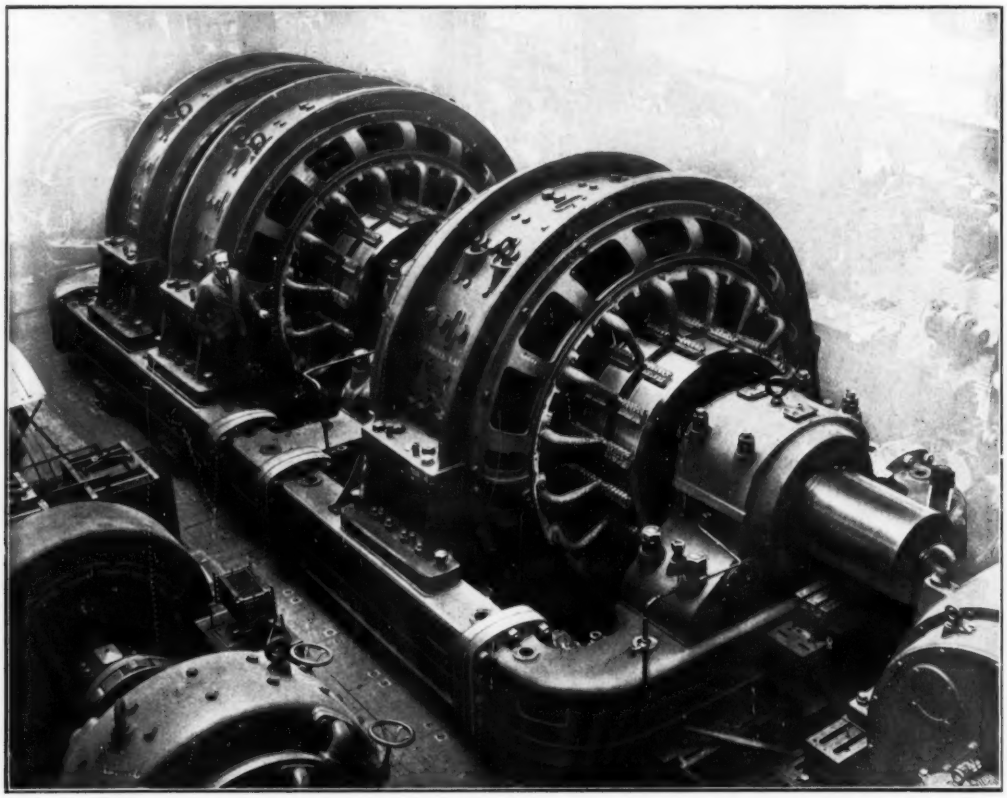


Fig. 1.—General View of 19,000 H.P. Reversing Mill Motor on Test-bed at Stafford.

An interesting example of the adoption of the electric drive for a large Reversing Mill is afforded by the electrical equipment at present being installed in Messrs. Cammell Laird's Steel Works at Penistone, near Sheffield, this plant being the second of two similar equipments recently put down by the English Electric Company to deal with the roughing and finishing of steel sections up to the largest sizes.

The mill, as originally installed, was driven by a reversing steam engine, and consisted of two stands of housings—cogging and finishing with rolls of 34" diameter, and deals with ingots up to 45 cwts. in weight, 22" × 16" section.

With a view to increasing the output from the mill, and of dealing with sections requiring power in excess of the capacity of the present engine, it was decided to extend the mill by putting down an additional set of intermediate housings, and to drive this new set of rolls, together with the finishing pair, by means of an electric reversing motor, leaving the cogging rolls to be driven by the present engine, for the time being.

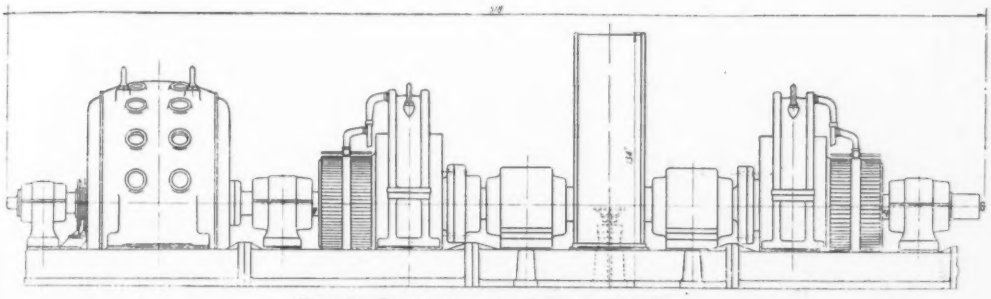


FIG. 2.—DIAGRAM OF THE FLYWHEEL SET.

When considering the lay-out, the substitution of a reversing motor for the cogging end has been borne in mind, and arrangements have been made so that the extension of the plant in this manner can be simply carried out.

The motor for driving the roughing and finishing train is designed for a maximum cut-out turning moment of 225 metre-tons at any speed between 0 and 60-R.P.M., corresponding at this latter speed to approximately 19,000-H.P., and Fig. 1 shows a general view of the motor as erected on the test bed at the Siemens Works, Stafford, where it was built.

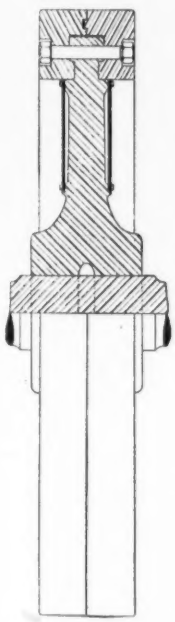


FIG. 3.
THE FLYWHEEL.

To deal with the long finishing passes which require high speed and relatively low torque, the motor has a further speed regulation from 60 to 150-R.P.M. by field weakening, and is capable of giving full horse-power throughout this speed range.

It will be seen from the illustration that the motor is of the three-armature design. Two of the machines are bolted together, back to back, and carried in two bearings, and the third armature, which is similar in all respects to the other two, is bolted to a coupling piece fitted to the shaft extension of the second armature, and is carried by an outer bearing. This gives three bearings for the complete machine.

The three-armature design was adopted, after much consideration, in preference to a double-armature design, for a number of reasons, of which the following are the most important:—

(1) The dimensions and weights of the armatures are reduced to limits which enable the machine to be manufactured in the shops and transported complete to site, and when there handled with reasonable facility.

(2) It renders possible the adoption of a standard single machine which, when built up as a single, double and treble unit, gives three powers, which meet the requirements of the usual sizes of mills employed.

(3) The moment of inertia of the rotating parts is very considerably reduced, which is of importance from the point of view of quick acceleration and the power required to accelerate.

A few leading particulars of the mill motor are as follows:—

Weight of each armature ...	approx. 45 tons.
Weight of complete machine ...	approx. 320 tons.
Diameter of shaft extension at driving end	700 m/m.
Overall length	approx. 45 ft.
Overall width	approx. 18 ft.
Voltage applied to mill motor armatures	1,400 volts.
Maximum cut-out current ...	approx. 11,500 amps.

The design of a reversing motor differs considerably from that of the standard commercial machine, in view of the loading conditions and rapid reversals required. Under ordinary working conditions the load demand may vary from zero to a maximum 8 to 12 times per minute, and a similar number of reversals in direction of rotation is required. Such conditions can only be met by a particularly robust design, both electrically and mechanically.

The motor is shunt wound and fitted with main poles, commutation poles and compensating windings, the latter, as well as the armature bars,

having moulded-on micanite insulation. The electrical constants are so chosen that the machines can readily deal with the heaviest loading conditions, which are in excess of three times the normal rating of the machines.

The special mechanical features are the employment of steel castings throughout, the adoption of a dove-tail and double key system of fixing the core plates to the spider to ensure no relative movement—a point of greatest importance—and the special fixing of the overhang of the armature windings to prevent racking of the same on the reversals.

Each armature is provided with its own short piece of shaft, the mechanical connections between the armatures being made by a special coupling piece of the same diameter as a large flange cast in one with the spiders. The function of the coupling piece is to register the armatures correctly and to permit the insertion of special driving keys so that the bolts holding the armatures together take no portion of the driving strain. This method of coupling the armatures eliminates a through shaft and gives a much more rigid construction with less deflection between bearings.

The pedestals, as will be seen from the illustration, are of very massive construction, and the bearings are provided with oil rings and a forced system of lubrication. It has been found that, under normal working conditions, the oil rings have proved sufficient to ensure lubrication.

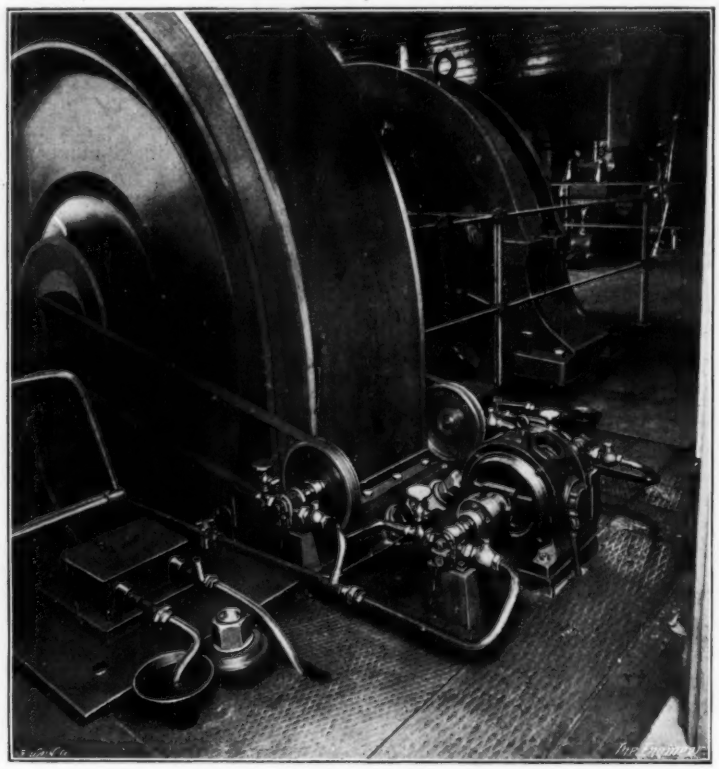


FIG. 4.—METHOD OF LUBRICATION.

The motor, on account of its comparatively slow speed and frequent stoppages, is not self-cooling, and a system of forced ventilation is employed whereby a volume of 40,000 cubic feet of air per minute is filtered and blown through

ducts into air trunks at the back end of the machines and distributed by suitable baffles through the armatures and fields.

The control of the mill motor is on the Ward-Leonard system, and the necessary supply is obtained from a motor generator set with a heavy flywheel operating on the Ilgner principle.

This motor generator set supplies the widely fluctuating power required by the mill motor, whilst the demand from the mains is practically constant. This result is brought about by making use of the stored energy of the flywheel during periods of heavy load by automatically reducing the speed of the flywheel set and re-inserting energy to the flywheel during periods of light-load, i.e. again speeding the flywheel up.

Fig. 2 shows diagrammatically the lay-out of the flywheel set, which from left to right consists of :—

A 3-phase driving motor.
A variable voltage generator.
A 46-ton, 14′ 3″ diameter flywheel.
A second variable voltage generator.

The whole of the plant is mounted up on a solid combined bedplate and is supported in five bearings.

It will be noticed that the variable voltage generators are placed one on each side of the flywheel, the armatures being solidly coupled to the flywheel shaft. This makes a very compact arrangement and reduces the energy to be transmitted through the flywheel shaft to a minimum.

The motor driving the set is of the 3-phase induction type, capable of giving continuously an output of 3,750 H.P. when working on a 3,000-volt, 50-cycle, 3-phase supply, and running at a synchronous speed of 428 R.P.M.

The variable voltage generators are designed to supply the mill motor when working in series, the combined maximum output being approximately 11,500 amps. at 1,400 volts. The peak demands of the mill motor must be directly taken by these generators, which are consequently again of special construction, the core centres and frames being of cast steel.

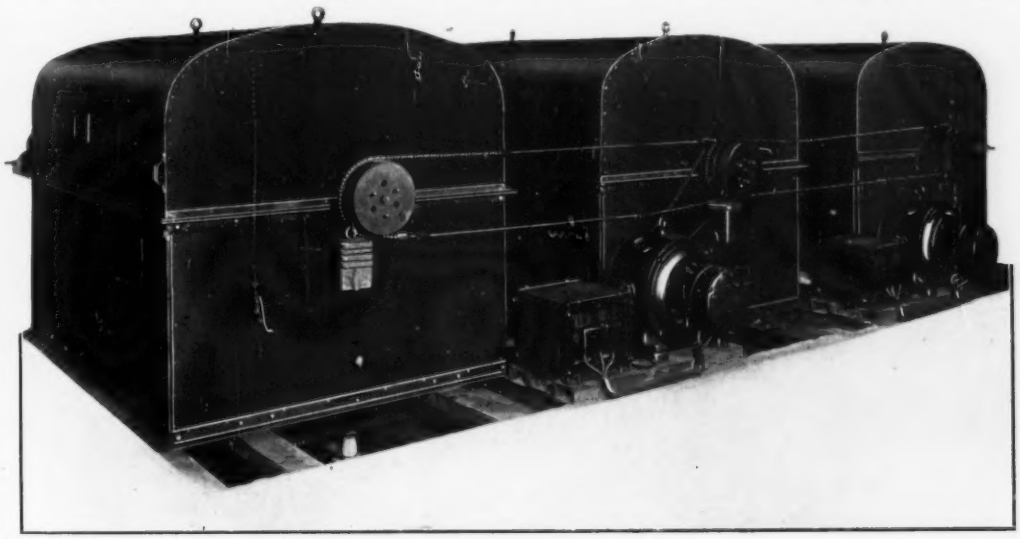


FIG. 5.—AUTOMATIC SLIP REGULATOR.

The flywheel adopted is of the built-up type, which is considered preferable to the complete cast steel wheel, owing to the simpler castings involved and subsequent elimination of stresses. A general idea of the design is given by Fig. 3.

The spider is a steel forging, and the complete half rings forming the rim are of cast steel and dove-tailed on to the spider, being held in place by through bolts.

The balance of these wheels when running with a peripheral speed of approximately 20,000 ft.

per minute has been found to be perfect, and the system of forced lubrication employed for the bearings is so efficient that it was found when balancing the wheel on site that the oil, under pressure which is introduced at a slight angle to the shaft, was sufficient to start the wheel rotating.

A duplicate system of forced lubrication is employed for the flywheel bearings, the oil pumps in the one case being driven by belts from the shaft, and in the other case by a small motor, this latter being used in case of emergency and when starting up the plant. This arrangement can be clearly seen from Fig. 4, which also illustrates the type of wind-shield fitted to reduce the windage losses to a minimum.

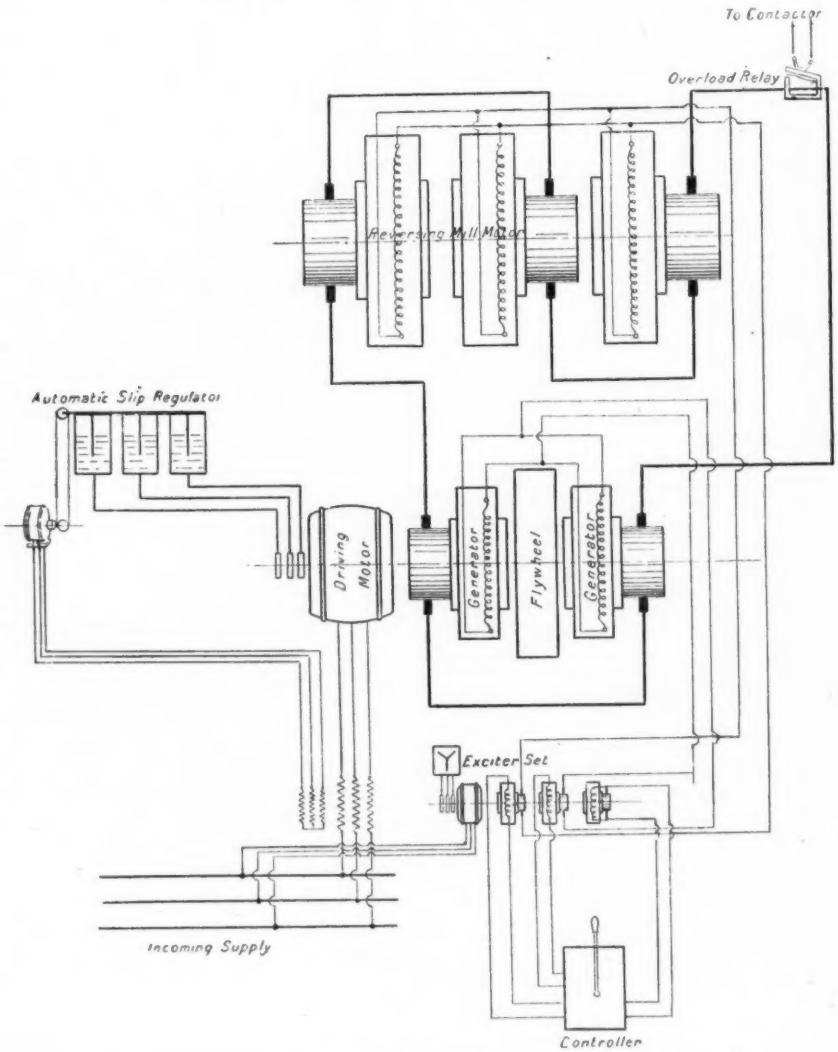


FIG. 6.—DIAGRAM OF CONNECTIONS.

The flywheel shown by Fig. 4 was supplied for a reversing equipment in Monmouthshire, but the general design is the same as in the present instance.

The working speed of the flywheel set is between 420 and 336 R.P.M., and this speed reduction is brought about by means of an automatic slip regulator, Fig. 5.

The principle employed is to insert resistance in the rotor of the 3-phase motor driving the flywheel set, causing a fall in speed at such times as energy is required from the flywheel, and to cut this out during periods of no-load in order again to speed up the flywheel.

The control is carried out by means of the two torque motors seen in the foreground. These motors are energized by the stator current flowing to the 3-phase driving motor. Under normal current conditions, the torque of the motor balances the effect of the weights, which tend to insert metal blades more deeply into a liquid solution. If the current to the driving motor tends to rise, the torque of the motors overcomes the weights, raises the blades in the liquid, thus inserting resistance and causing a slowing down of the flywheel set. As soon as the current to the driving motor falls below normal, the reverse action takes place, the weights insert the blades further into the liquid, which reduces the resistance, and causes a speeding up of the flywheel.

The control of the speed and direction of rotation of the mill motor is carried out by a control lever with a simple backwards and forwards movement, the central position of the lever corresponding to a state of rest on the mill motor, whilst a movement in the one direction or the other gives a forward or reverse direction of rotation on the mill motor, the speed of the

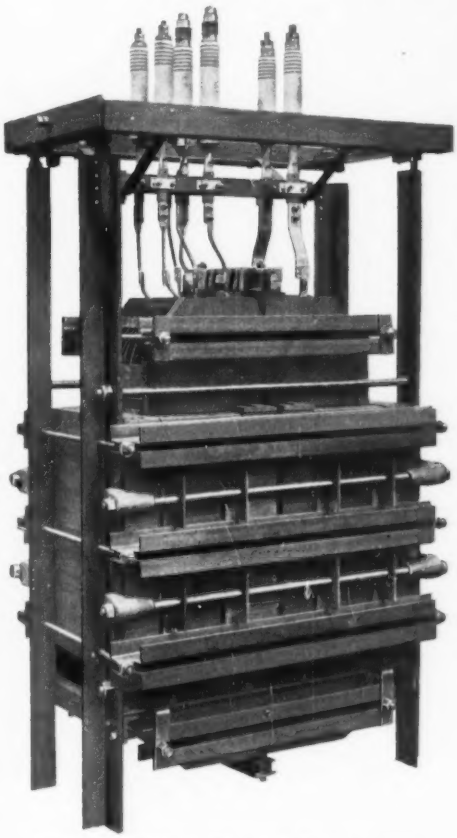


FIG. 7.—INTERNAL VIEW OF TRANSFORMER.

FIG. 8.—EXTERNAL VIEW OF TRANSFORMER.

motor bearing a definite relation to the position of the lever. This control lever is mounted on a platform arranged above the live roll track of the finishing mill. The control lever operates resistances in the fields of an exciter set, the armatures of which supply the current for the fields of the main mill motor and variable voltage generators. It will thus be seen that the actual currents to be controlled are extremely small, and the controller is of the simplest description.

Mounted alongside the control lever is an instrument desk which carries the necessary instruments to show the driver what is taking place; thus an ammeter gives him the power demanded from the mill motor, and a speed indicator gives the speed of rolling. A further speed indicator makes him aware as to the speed of the flywheel set, and if this is reduced to the bottom working limit a red lamp lights up and warns him that it is necessary to roll slowly until the speed of the flywheel has been recovered.

A typical diagram of connections is shown in Fig. 6.

The incoming power supply, which is obtained from the Yorkshire Electric Power Co., is generated at 10,000 volts, and is transferred down on sight by means of suitable static transformers to 3,000 volts, at which pressure it is delivered to the motors of the flywheel set and exciter set.

The transformers are of the single-phase, oil-immersed, self-cooling type, and three of them are arranged to form a three-phase bank, while a fourth is held as a spare.

Figs. 7 and 8 show an internal view and the type of tank supplied for the transformers, and attention may be drawn to the concentric terminal adopted, which is shown in the former view.

The transformers themselves are of the sealed type, i.e. the case is completely filled with oil under a slight pressure head.

To meet varying voltage conditions, it is frequently necessary to have tappings on the transformers to enable a constant voltage to be obtained from the secondary, with a varying primary voltage. The concentric terminal has been evolved to enable a change of tapping to be easily effected, the connections to the different tappings of the transformer being brought up through the concentric terminal to metal rings at the top, on to which clip connectors are attached. It is thus rendered unnecessary to break the seal when altering the connections.

In order not to interfere more than necessary with the floor space of the mill, the mill motor itself is the only portion of the plant on floor level, the flywheel set, exciter set, slip regulators, transformers and other plant being erected below ground in a chamber approximately 103 ft. by 76 ft.

The transformer chambers lie along one wall of the station, and are separated from the remainder of the plant by means of a wall. Each transformer is mounted in its own cell with concrete walls and a sheet metal door. To give ease of movement, each transformer is mounted on a track, which can be drawn forward out of the cell on to a bogey which runs at right angles thereto, This bogey runs on lines which lead directly under the crane.

The fact of the plant being below ground necessitates special arrangements for ventilating purposes, and, in all, three motor-driven fans, each capable of blowing 40,000 cubic feet of air per minute, are installed, the functions of these being divided out, as follows:—

One supplies air to the transformer chambers.

One supplies air for the main machinery, the air ducts opening up under the machines of the motor generator flywheel set.

The third fan delivers its air direct to the mill motor.

The incoming air is drawn from a distance, which ensures comparatively clean condition, but the whole passes through dry air filters, of the cloth type, built in a separate chamber away from the plant, where the dust content is removed.

Overloads on Commutating Machines.

By W. E. Highfield and J. E. Calverley.

The effects of overloads on commutating machines have become of increasing importance on account of the larger size of modern units and the higher speeds at which they run. Another exceedingly important factor is the higher voltages at which modern railway systems operate, which has immensely increased the severity of line short-circuits. It is with the last conditions that this paper principally deals.

The short-circuits on 1,200 and 2,400-volt railway systems are exceedingly severe, and it is necessary that the station and substation plant be capable of withstanding such shocks, or that they be protected from them.

The old standard form of 500-volt circuit breaker is not sufficiently fast in operation to protect the machinery from a short-circuit severe enough to produce a flash-over. This type of circuit breaker operates in about 0·1 second, and recent investigation has shown that the short-circuit current in an armature may grow at the rate of one million amperes per second. Obviously such a circuit breaker will not operate sufficiently quickly to protect the machinery and to meet the conditions development has taken place along certain defined lines.

First, the circuit breakers have been improved, and these can be obtained capable of opening the circuit in 0·001 second. Such a circuit breaker is very large and expensive, but station engineers will recognize that insurance against flash-overs is worth paying for. Attention has also been given to the machines, and several elaborate systems of spark guards and barriers have been designed that have given satisfactory results.

These methods are the obvious ones to pursue, but they really do not touch on the cause of the flash-over, which lies in the machine itself.

A more elegant solution, patented by the Westinghouse Company, combines a high-speed circuit breaker short-circuiting a set of three-phase slip-rings fitted to the direct-current armature for that purpose. The circuit breaker is set to operate at a pre-flash-over current, and the short-circuiting of the three-phase slip-rings reduces the D.C. voltage to zero, effectively preventing a flash-over.

To illustrate the nature of a flash-over it is necessary to know what occurs in the armature and field of a commutating machine under short-circuit conditions. A 300-K.W. machine has been taken and run under varying conditions and the results investigated. This machine was a plain compensated high-speed machine, and could be run either as a D.C. generator or motor, or a 50-cycle rotary converter. The particulars of the machine are as follows:—

No. of poles = 4.
R.p.m. = 1,500.
Volts = 500.
Amperes = 600.
Armature = 24 in. diameter × 16 in., with four $\frac{3}{8}$ in. air ducts.
Commutator = $13\frac{1}{2}$ in. diam. × 27 in. long, with 3 shrunk rings.
Brushes = 16 per pole, each 1 in. × 0·7 in.
Slots = 84, size 0·48 in. × 1·2 in.
No. of conductors per slot = 4.
Winding = parallel with 9 equalizing rings.
No. of commutator bars = 168.
Compensating winding = 10 slots per pole, with 2 conductors per slot.

The contributory causes to flash-over are:—

Sparking.—This is present when the interpolar field is insufficient or incorrectly distributed so that the coils short-circuited by the brushes do not lie in a suitable field. The reactance voltage set up by the short-circuit current in these coils is not neutralized, and there is a considerable E.M.F. broken where the commutator bar leaves the brush edge. Sparking will also occur when the current density is too high in the carbon brushes. This also is the result of incorrect distribution of the interpolar field, and a very large current passes across the surface of the carbon round the coils under short-circuit. As the commutator bars are leaving the brush by the rotation of the commutator so the contact area decreases and the current density rises to infinity. Intense glowing occurs, hot gasses are given off, or the carbon may even break up.

The effect of sparking, from one cause or another, is to reduce the effective distance between the positive and negative brushes, and it also reduces the insulating value of the air by the generation of hot gases which are drawn around the commutator surface by its rotation. The insulating properties of the air are still

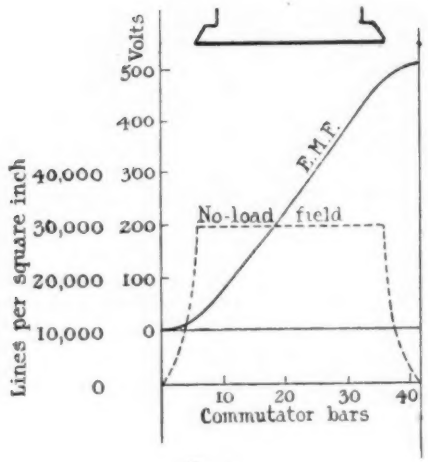


FIG. 1.

further reduced by the dust from the carbons, and these particles are generally in a state of incandescence.

Field Distortion.—The distortion of the main field is caused by the reaction on it of the field set up by the armature. The resultant field may be such as to produce a very unequal distribution of the voltage around the commutator. It is this problem of the distribution of the field that is so difficult to pre-determine. Voltage-distribution curves were taken on the test machine under different conditions, and corresponding calculations were made and checked against them. A great deal of tedious work was involved, but the final result fully justified the trouble, for eventually the curves could be calculated to check with the actual figures within a permissible error.

In the sequence of tests the machine is first considered as a plain D.C. generator, the compensating winding being disconnected. Fig. 1 shows the no-load magnetic distribution and the resultant voltage.

Fig. 2 shows the machine at full load, viz., 600 amperes. The effect of the armature field on the main field is clearly shown. The voltage curve rises very steeply from bars 8 to 38, the other bars doing almost nothing, and the maximum voltage per bar has been materially increased.

Fig. 3 shows the machine at five times full load (3,000 amperes.)

The effect is most marked. What is called the neutral point, that is the line on which the brushes lie and from which the voltage should commence rising, has been drifting forward until it lies well under the pole. The windings of the machine are trying to act in both a motoring and a generating direction. The total voltage over the 42 bars is now 1,750, although the resultant voltage above the zero line is only 525.

The maximum voltage across the commutator bars occurs across numbers 27 to 32.

There is a pressure of 500 volts across these five bars, or 100 volts between any pair. The mica segments measure 0·03 in. each, so the striking distance through air is only 0·12 in., and it must always be remembered that the dielectric strength of the air will be very much reduced by the hot gases and incandescent carbon dust present across these surfaces. To put it another way, the insulation can be considered as being only, say, 50 per cent. effective, so that instead of 0·12 in. being the striking distance, it is only 0·06 inch for 500 volts.

The distortion would be still greater if it were not for the effect of saturation. The iron circuit

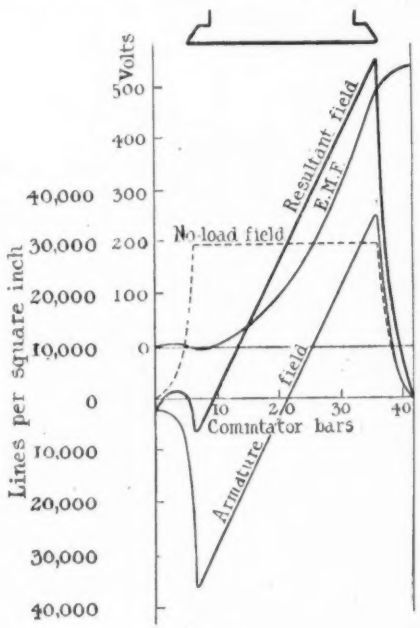


FIG. 2.

becomes saturated in the neighbourhood of 150,000 lines per sq. in., and has then practically the same permeability as air. In the given load conditions the armature ampere-turns are 31,500, whereas the main field is only 3,750. The difference, 27,750 ampere-turns, is sufficient to saturate the iron circuit of the machine, and any excess above this is absorbed in the leakage field. It is quite obvious that the machine will flash over before the conditions in Fig. 3 are reached, and such is actually the case, but the figure is most instructive as showing the forms taken under such severe conditions, and conditions, moreover, that are not approaching a short-circuit.

For a machine to comply even in a measure with short-circuit conditions either interpoles or a compensating winding, or both, are required. For further tests the compensating winding was put in circuit. This winding consists of conductors laid in slots in the pole face, and as there are 10 slots with 2 conductors in each, the winding gives 6,000 ampere-turns at 600 amperes' load. The armature ampere-turns at this load are 6,300.

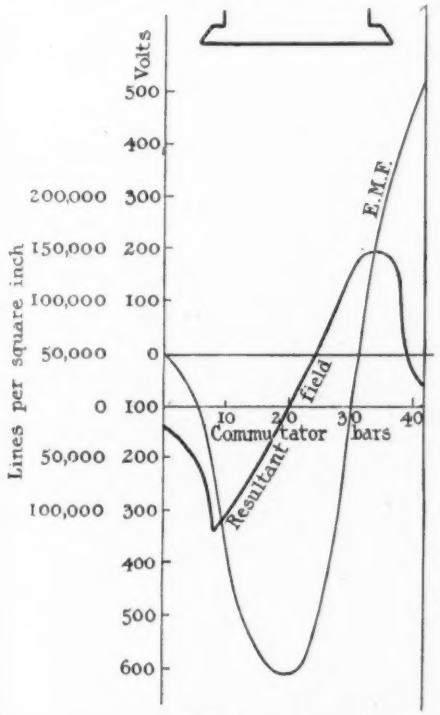


FIG. 3.

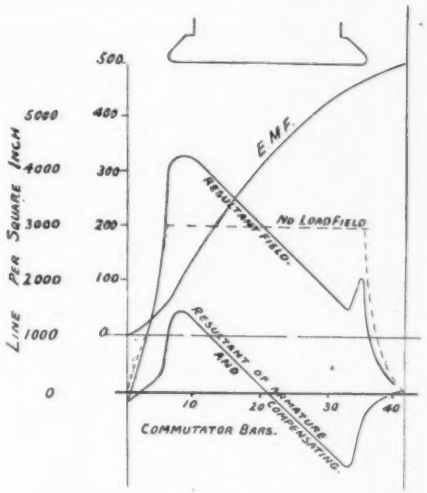


FIG. 4.

The effect of the compensating turns is only partial, due to the existence of the air gap and the interpolar space. As the interpolar space reduces the length of the pole, so the compensating winding has to be concentrated as compared with the armature, to avoid undue densities in the pole teeth.

If a machine could be made without an air gap and without the interpolar space, complete compensation could be obtained by using a winding identical with the armature winding. As this, unfortunately, cannot be done, the concentrated winding is used

The fact that practical compensation is only partial is not generally recognized, but the subsequent figures show that very unexpected results can and do obtain under abnormal loads, particularly with reference to the distribution of the field in the interpolar space.

Fig. 4 shows the distribution of the field and the resultant voltage at a load of 600 amperes.

The average voltage per bar, that is the terminal voltage divided by 42, the number of commutator bars, is 11·9, but due to the distortion of the field and the interpolar space the maximum voltage in Fig. 4 is actually 22 volts. This occurs between bars 7 and 9. The general effect of the compensating winding tends to change the true neutral position where the brushes lie, and in this case the shift is

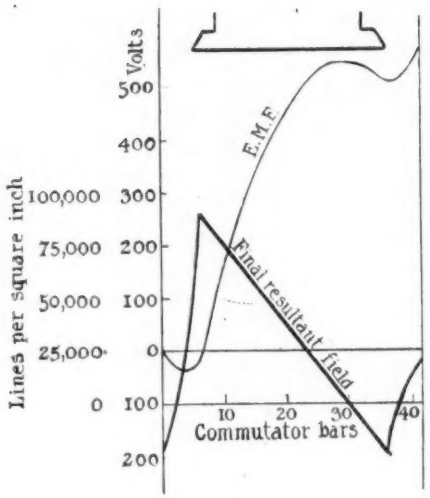


FIG. 5.

backward in the direction of producing a commutating field at the neutral position. In Fig. 5 the load has been increased to 5 times full load (3,000 amperes).

There is a negative commutating field which will add to the reactance voltage of the short-circuited coils and cause severe sparking. The maximum voltage per bar is 47 between bars 7 and 8.

By increasing the strength of the compensating winding a positive commutating field can be obtained sufficient to neutralize the reactance voltage of the short-circuited coils, but the peaks of the main field would be still more pronounced, the maximum voltage per bar would be increased, and the machine would be in a very unstable condition. The surface insulation of the commutator, somewhere between the positive and negative brushes, would be heavily stressed, and this is the point where the flash-over would commence.

There are many machines running with an excess of compensating turns to armature ampere-turns. An excess of as much as 75 per cent. is not uncommon, and such machines will run well at full load and small overloads. But such a design is quite unsuitable to meet short-circuit conditions; it would inevitably flash over. Even on normal loads there have been many cases of over-compensated machines flashing over without any apparent cause. One moment they are running perfectly and then without any observable change in load or running conditions a flash-over occurs. This phenomena is due to very small causes. An excess of incandescent carbon from newly-bedded brushes, a slight dragging of minute copper particles over the micas, is sufficient to start a flash-over.

Experience with some 500-K.W. 5,000-volt generators was very instructive on this point. The armature field was very strong, but not unduly so with regard to the main field opposing it. Still the commutators were very highly stressed from a surface insulation point of view.

The pole span being wide there was a great distance between the positive and negative brushes, and it was possible to see the commencement of the flash-over. This did not start with sparking at the brushes but sprang from some point about midway between. The machine would be running quite sparklessly and would flash over without apparent change in conditions. The cause was generally traced to minute copper bridges dragged over the mica insulation by the friction of the carbons. Undercutting the mica stopped this trouble.

In D.C. machines the magnetic distribution of the field requires to be very carefully predetermined. The compensating turns must be designed to balance equally the armature field along the pole face only. This winding should be distributed as widely as the magnetic densities in the pole teeth permit, and it is better to be on the under than the high side with the compensating field.

An interpole must be designed to give the commutating field and to carry any additional compensating turns that may be required to give the correct distribution in the interpolar space.

A plain interpole design is not the best if short-circuits are likely to be frequent.

In this type of machine an auxiliary pole is provided midway between the main poles. The winding carries the armature current, and the magnetizing force is therefore proportional to the load of the machine. The winding carries turns equal to the armature reaction plus a sufficient amount to provide the correct commutating field and the leakage. This is a very insufficient compensation of the armature field, since it occurs at one point only. If a pole-face winding is too concentrated to provide perfect compensation, how much more so must be the case when the winding is carried in what is practically one slot.

Then it is difficult to get sufficient iron into the interpole to make it give a fairly straight-line field proportional to the magnetizing force. This is always a point of difficulty with the design of interpoles. A further complication is caused by a point not usually taken account of. The calculations for the reactance voltage of the short-circuited coils are of an empirical character, but all of them give straight-line results. That is, if the calculated reactance voltage is 5 at 1,000 amperes' load it will be 10 at 2,000 amperes' load. Actually this is not so, for, under extreme overloads, the ampere-turns of the short-circuited coils are sufficient to saturate the armature teeth, and the actual reactance voltage is much less than calculated by the straight-line law.

It is advisable to calculate the reactance voltage as a curve at various loads and to choose an interpole that will meet the average requirements, even though this means sparking at some point due to too strong a field.

In the case of rotary converters the problem is a different one because the effect of the armature field on the main field is somewhat different.

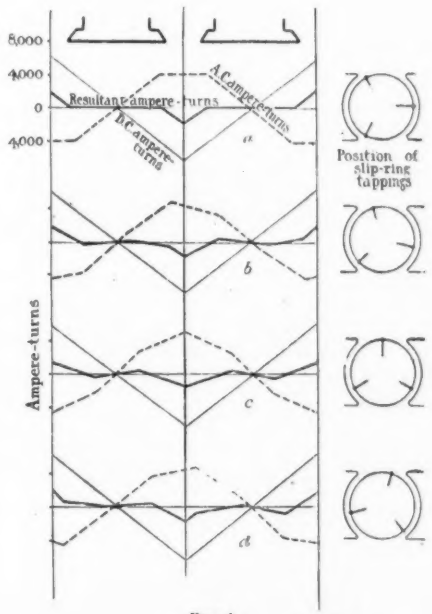


FIG. 6.

In a D.C. machine the magnetizing force of the armature is at a maximum at the centre of the interpolar space, and is zero at the centre of the pole that is halfway between the positive and negative brushes. The armature field directly detracts from or adds to the main field, and the resultant is the actual field obtained. Any change in the armature current directly affects the distribution of the flux.

But a rotary is both a synchronous motor and a D.C. generator, so that it receives alternating current from the three-phase supply mains and gives out current to the D.C. mains. The input and output can be considered as equal and opposite, and as the magnetizing force set up by the alternating current has practically the same distribution as that set up by the direct current, the two cancel out and the final magnetizing force of the combined currents is zero or nearly so. If the field set up by the A.C. armature reaction is plotted at any instant throughout one complete cycle, it will be found to differ according to the angular displacement of the slip ring tappings.

Fig. 6 (*a* to *d*) shows the armature reactions in a rotary converter plotted with a varying angular displacement of 15 degrees. The variations then repeat, making 8 times to the complete cycle. These variations give a pulsating effect to the field which particularly affects that portion in the interpolar space.

The resultant effect of the D.C and A.C reactions give the rotary converter the characteristics of a compensated machine. This compensation is a varying quantity. In Fig. 6*a* along 90 per cent of the pole face it is perfect, but in Figs. 6*b*, 6*c*, and 6*d* it is not quite so good. In the interpolar space it is not, strictly speaking, any more compensated than in a D.C. machine. But it is much superior to the D.C. machine because the reactive magnetizing force in the interpolar space does not rise to so great a strength as in the latter.

In Fig. 7 the flux and voltage curves are plotted for full load, i.e. 600 amperes. In Fig. 8 the curves are plotted for 10 times full load, conditions which are approaching a short-circuit. In this figure the field, in which the coils under short-circuit lie, is negative to the extent of 18,000 lines per square inch, which will add to the reactance voltage in those coils. The depression in the curve at the centre, due to the imperfect compensation of the armature reaction, is small, especially in comparison with the D.C. curves. It is not sufficient, in itself, to disturb the voltage

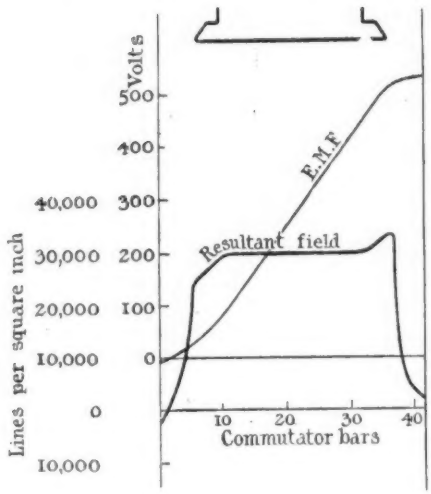


FIG. 7.

gradient to any extent, the difference being from 12 to 18 volts per bar. But the distortion in the interpolar space is most important. The negative field produced at the point of commutation will add to the reactance of the coils under short-circuit about 9 volts. The reactance voltage itself, allowing for saturation, is 30 volts at 6,000 amperes' load, making the total E.M.F. in the short-circuited coils 39 volts, which in itself is sufficient to produce such violent sparking as would lead to a flash-over.

In all these curves the A.C. armature reaction is the mean reaction, the pulsating effect shown in Fig. 6 being confined to the change in ampere-turns and the frequency being too high for the effect to be reflected on the flux. Also the power factor is taken at unity throughout, although this will not be the case at final short-circuit. It must be considered that the final reaction of the armature windings affecting the main field is the difference between the A.C. and the D.C. ampere-turns, and these under final short-circuit will not coincide as in the curves up to 10 times full load. The reason is that on final short-circuit a large D.C. current flows and the excitation voltage no longer exists and consequently the field falls. A magnetizing current is now drawn from the A.C. supply to maintain the back E.M.F. This causes the power factor to fall and the A.C. reaction ampere-turns are no longer in the same direction relative to the field, which will make the conditions still worse than those shown in Fig. 8, especially in relation to the voltage distribution round the commutator. Also, due to the wattless component and its effect in shifting the direction of the A.C. reaction, the negative part of the voltage curve is increased.

Another point must be considered in connection with rotary converters and in which they differ from D.C. machines. Suppose an exceedingly heavy overload is thrown on a D.C. machine and the circuit breaker opens; instantly the machine is relieved, for the change in ampere-turns due to the opened circuit is simultaneously felt in the armature reaction, the compensating and the interpole fields, and the no-load distribution is established. But with a rotary converter it is different. On the opening of the circuit the D.C. reaction field alone disappears. A heavy current is still being drawn from the A.C. supply circuit, so the full armature reaction due to the alternating current will be imposed on the main field because there is no longer a D.C. reaction to compensate it. The main field will then be distorted in proportion to the A.C. reaction, and these conditions hold until the back E.M.F. is readjusted. When the machine is interpolar the conditions for commutation are made still worse under these conditions. A rotary interpole only carries sufficient turns to provide the necessary

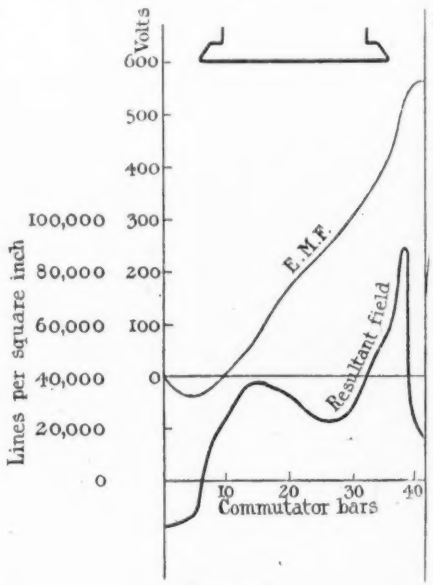


FIG. 8.

commutating field and compensate for the difference between the A.C. and D.C. reactions. If the D.C. reaction is wiped out, obviously the remaining A.C. reaction will overcome the interpole field, and the interpole itself provides an iron circuit for the lines, created by the armature reaction, to close round. A rotary converter may therefore flash over after the circuit breaker has opened. Considering the whole matter now in a general sense it can be said that a D.C. machine, by carefully proportioning the compensating and commutating windings, can be made almost immune from flash-over when protected by ordinary standard circut breakers. The problem can be made easier if the station engineers will accept rather more conservative speeds than those for ordinary 500-volt machines. A moderate-speed machine is immensurably superior to a high-speed set. The smallest inequality in the commutator surface of the latter will cause sparking. The brushes actually jump from the commutator surface, and the commutator travels some distance before the brushes again make contact, and a severe spark is inevitable. With a lower surface speed the brush will follow a reasonable inequality in the commutator without breaking contact.

To make the rotary converter immune from flashing is a more difficult problem than that of the D.C. machine on account of the more complicated reactions. But by carefully proportioning the various fields, almost complete compensation can be obtained. The utmost stress is laid on the study of the field distribution under the varying conditions of load and overload to enable the desired result to be obtained. Afterwards the addition of spark guards and other apparatus may be considered, but this question should always be kept subordinate to the machine design itself, which is the root of the matter.

PHOENIX PARK, BRADFORD: A CORNER OF THE GOLF LINKS.

Overall Economy in Steam Power Stations.

By E. R. Briggs, M.Inst. C.E., M.I. Mech. E.

In *Engineering*, November 13th, 1914, Mr. R. H. Parsons contributed an article entitled "The Law of Power House Economy." Mr. Parsons found by plotting the steam and coal used per eight-hour shift of a Canadian Power House against the Kilowatt hours generated during the shift that the results gave straight line laws. A further straight line law is also obtained by combining the two, that is, plotting the steam against the coal. With the general conclusions and the laws themselves, with one exception, we are not concerned. The exception is the one relating to the coal consumed as a function of the units generated; setting out from this law, it is proposed to develop in the present article a method of obtaining curves showing the performance of power stations at varying load factors.

Mr. Parsons' Law, with which we are concerned, is written—

$$C = a + b.K \quad \ldots\ldots (1)$$

where

C = coal burnt per 8-hour shift, in lbs.

K = total units generated in 8 hours.

a and b are constants.

The constant a represents the coal consumed in lbs. per shift, to provide for the constant station losses, such as steam leakage, radiation and general stand-by requirements. An additional amount of b lbs. of coal per K.W.-hour is needed to make the total coal consumption. It is of interest to note that the constant a is largely a measure of the Boiler House efficiency. Only by rigid boiler house control can a be kept down; the other constant b is determined by the efficiency of the machinery—boilers and turbines—operating.

It has been claimed on behalf of the Parsons' Law that it provides a means of comparing the working of the station with that of other plants, irrespective of size and output. This is not correct, since it is obvious that the constant a will vary with the capacity of the station (probably in direct proportion for equally efficient boiler houses; but a large number of results would be necessary to confirm this).

Referring to equation (1), if we write C_1 as the average coal burnt per K.W.-hour during the shift (1) becomes—

$$C_1 = \frac{a}{K} + b \quad \ldots\ldots (2)$$

Since K is the total units generated per 8-hour shift, it can also be expressed—

$$K = 8.M.L. \quad \ldots\ldots (3)$$

where M is the maximum load in K.W. during the shift, and L is the load factor. Consequently (2) may be written –

$$C_1 = \frac{a}{8.M.L.} + b \quad \ldots\ldots (4)$$

It is, however, very convenient to record the overall efficiency of a Power Station in terms of heat units (H) in the fuel required to give one Kilowatt hour at the switchboard; if T is the calorific value of the fuel in B.Th.U. per lb., equation (4) becomes—

$$H = \left(\frac{a}{8.M.L.} + b\right) T \quad \ldots\ldots (5)$$

Mr. Parsons gives, for his Canadian Station, the following values :—

$a = 20{,}000$

$b = 2{,}917$

T = 10,100 B.Th.U. per lb. of dry [fuel.

Rated capacity = 80,000 K.W.-hours per shift.

The above values a and b were taken during the month of September, 1914, ninety records being plotted, covering a range of output varying from 4,500 to 24,300 K.W.-hours per shift.

Since the rated capacity was 80,000 units per shift, the plant capacity was 10,000 K.W., and we may assume M to have an average value of 8,000 K.W. Substituting these values in (5) we get

$$H = \left(\frac{0{\cdot}3125}{L} + 2{\cdot}917\right) \times 10{,}100 \quad \ldots\ldots (6)$$

the curve being plotted on Fig. 1. Since $b = 2{\cdot}917$ or 29,450 B.Th.U. per K.W.-hour at the switchboard, this represents the net heat consumption of the boilers and turbines. It is convenient to take this as a basis and plot the percentage increase from 100% load factor downwards; this curve appears in Fig. 2. At 100% load the increase in fuel consumption is 10·7% rising to 21·6% at 50% load, and 54·3% at 20% load factor.

In order to make a comparison with these figures for an English Power Station, the results, as obtained by the Parsons' Law, are taken from the North Metropolitan Electric Power Supply Company's Station at Willesden. Mr. Napier

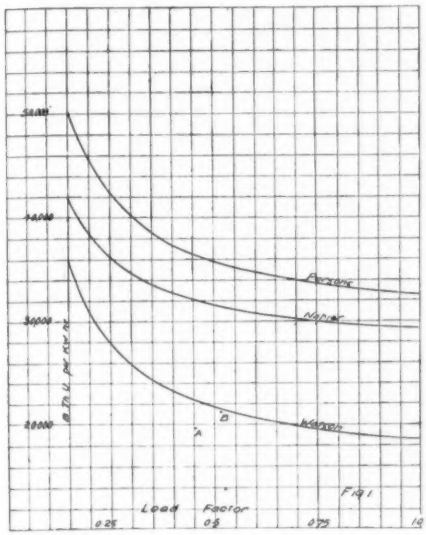


FIG. 1.

finds (see *Engineering*, Feb. 8th, 1918, p. 152) that

$$C = 17{,}000 + 2{\cdot}17\ K.$$

the rated capacity of the main generators aggregating 15,000 K.W. Notwithstanding the fact that the capacity is 50% larger than Mr. Parsons' plant, the value of a is actually less, which indicates a more efficient boiler-house plant. Also, as b is 2·17 as against 2·917, shows that the prime movers are, on the average, more efficient. A direct comparison cannot, of course, be made, because such factors as steam pressure, superheat, vacuum, etc., are not given. Treating Mr. Napier's figures in the same way, and assuming the calorific value of the fuel to be 12,500 B.Th.U., and taking M at 12,000 K.W., we find that

$$H = \left(\frac{0{\cdot}177}{L} + 2{\cdot}17\right) \times 12{,}500 \ldots\ldots\ldots\ldots\ldots(7)$$

This is also plotted on Fig. 1 and the percentage increases, compared with 2·17 lbs. coal (=27,100 B.Th.U.), on Fig. 2. As expected, the figures are lower, being 8·1%; 16·5% and 41% as compared with 10·7, 21·6 and 54·3 for the Canadian Station for 100%, 50% and 20% load factor, respectively.

This method of expressing the Parsons' Law is of peculiar advantage when forecasting Power Station efficiencies, and as an example in this direction we may take four figures, quoted by *Engineering* (June 21st, 1918, p. 699) from an address by Mr. S. J. Watson, before the Incorporated Municipal Electrical Association, at Manchester. The figures are those in the following words:—

"For a load factor of 33·5 per cent, he (Mr. "Watson) considers that the thermal efficiency "of the station may be 13·8 per cent, whilst "if the load factor can be raised to 45·7 per "cent, he thinks that a thermal efficiency of "15·3 per cent should be secured."

From this data we can add curves to Fig. 1 and Fig. 2, and work out the Parsons' Law for Mr. Watson's Station. Since a Kilowatt hour equals 3,413 B.Th.U. 13·8% efficiency = 24,730 heat units, and 15·3% efficiency = 22,300 heat units. Taking the calorific value of the fuel at 12,500 B.Th.U., C_1 (equation (2) above) equals 1·978 and 1·783 lbs. per K.W.-hour respectively. Actually Mr. Watson takes 2 lbs. and 1·8 lbs. respectively, corresponding to a calorific value of 12,400 B.Th.U. For L = 0·335, equation (4) becomes

$$1{\cdot}978 = 0{\cdot}373\,\frac{a}{M} + b\,. \ldots\ldots\ldots\ldots\ldots(8)$$

and for L = 0·457, we have—

$$1{\cdot}783 = 0{\cdot}2735\,\frac{a}{M} + b \ldots\ldots\ldots\ldots\ldots(9)$$

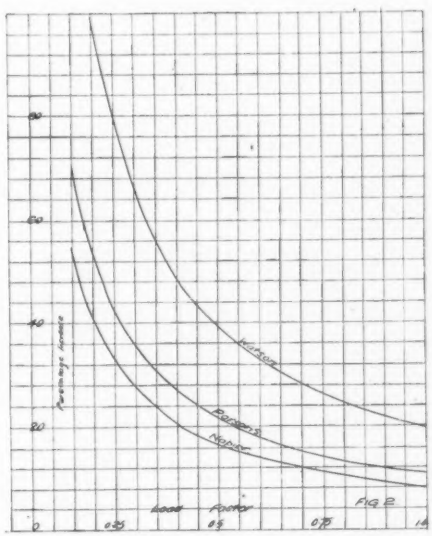


FIG. 2.

From these two (8) and (9)—

$$\frac{a}{M} = 1{\cdot}96 \text{ and } b = 1{\cdot}247$$

As Mr. Watson was discussing a proposed station of 100,000 K.W. plant capacity, and taking M as before, at 80 per cent. of the plant capacity, the Parsons' Law for such a station would be, in round figures—

$$C = 160{,}000 + 1{\cdot}25\ K.$$

which means that the fuel consumption for the net steam used by the boilers and generators at full load is only 1·25 lbs. per K.W.-hour, or a total heat supply of 15,600 B.Th.U. per unit, including boilers and auxiliaries as well as turbines. On the other hand, the value of a (160,000) appears to be high. A comparison of the three examples considered is of interest:—

	a.	Plant capacity in K.W.	Capacity a.	b.
Parsons	20,000	10,000	2·0	2·917
Napier	17,000	15,000	1·13	2·17
Watson	160,000	100,000	1·6	1·25

It would appear that Mr. Watson paid more attention to a high machinery efficiency rather than a high station economy. Curves for the B.Th.U. per unit have been added to Fig. 1 and the increased consumption as a percentage for varying load factors has been plotted on Fig. 2. The reason for the latter curve in Fig. 2 being so much higher than the others is, as explained above, due to the fact that a is high and b low, relatively.

The last two columns in the above table are worth a little consideration. As already stated, the figures given for a per K.W. station capacity, give approximately a measure of the Boiler House efficiency. In the operation of power stations the economy depends largely upon two factors, the first is the series of conditions over which the operating engineer has no control. They are limited by boiler pressure and superheat on the one hand, and cooling water temperature on the other; they also include such factors as site position with regard to water supply, and, if cooling towers are employed, the average weather in the locality. These, and others, have to be accepted as part of the hard facts that the operating man is up against. The second factor is one that is almost wholly within the operating engineers' control, and they consist of the general efficiency of the plant and its maintenance at a very high standard, with the elimination of all sources of waste. It is noticeable that the first factor is covered by the constant b, and the second by a per K.W. plant capacity, so that by comparing his returns from time to time on the basis of the modified form (equation 5) of Parsons' Law, the operating engineer can tell at a glance how his controllable efficiency is improving, and also whether his machinery is maintaining its guarantee, as well as recording comparative curves of the station efficiency as a whole. As an interesting comparison of a station in which the overall efficiency has gradually decreased, reference may be made to the Connor's Creek Station of the Detroit Edison Company. In the *Electrical World* of Sept. 20th, 1919, p. 656, a table is given of the production costs for twelve month periods ending each six months from June 30th, 1916 to June 30th, 1919. From these figures it is seen that although the annual load factor shows an increase from 40·9 per cent for the first period to 53·3 per cent for the later one, the coal per K.W.-hour steadily increased from 1·44 lbs. to 1·67 lbs. with a corresponding rise in the B.Th.U. per K.W.-hour from 19,700 to 21,200. These two figures have been added to Fig. 1 and are marked "A" and "B" respectively.

The writer would like to add that, in referring to Mr. R. H. Parsons' conclusions as "Laws," he is merely quoting Mr. Parsons' article, and does not necessarily endorse the claim to the title, which might be questioned on the ground that the "laws" cannot be proved mathematically. Probably Mr. Parsons himself does not use the word in this strict sense.

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